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THE POWER CATECHISM

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THE

POWER CATECHISM

Correct Answers to Direct Questions Covering the Main Principles of Steam Engineering and the Transmission of Power.

COMPILED FROM THE REGULAR MONTHLY ISSUES OF

"POWER"

Intended for Special Assistance in Preparation for Examinations or where Direct Information is Desired.

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PREFACE.

The catechetical form of presenting information appeals strongly to the practical man who wants rather a simple answer to a plain, practical question than an exposition of the principles involved. It has been employed in the columns of POWER, and a continuous demand for back numbers, long since exhausted, has led to this compilation of the matter so published. The catechism as originally published has been revised and extended by the introduction of pertinent matter from our "Questions and Answers" and other departments. The answers are in accordance with our latest knowledge and as complete as is consistent with the conciseness imposed by this method of presentation.

F. R. LOW,
EDITOR OF POWER.

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THE POWER CATECHISM.

SECTION I.

Classification of Boilers.

Q. 1 —Into what two general classes may boilers be divided?
A.—Internally fired and externally fired.

Q. 2 —What are the principal internally fired boilers?
A.—Cornish, Lancashire, Galloway, Drum or Scotch, Marine Flue, Marine Tubular, Firebox, Vertical.

Q. 3 —Name principal types of externally-fired boilers.
A.—Plain Cylinder, Return Flue, Return Tubular, Water Tube, Sectional, Coil.

Q. 4 —Give another classification of a more particular nature.

- Stationary Boilers
  - Cornish or Single Flue
  - Lancashire or Two Flue
  - Multiflue
  - Galloway
  - Plain Cylindrical
  - Return Flue
  - Flues and Return Tubes
  - Return Tubular
  - Fire Box
  - Vertical
  - Water Tube
  - Sectional
- Locomotive Boilers
- Marine Boilers
  - Older Types
    - Flue and Tube
    - Flue
    - Tubular
  - Scotch or Drum
  - Water Tube and Sectional

Q. 5—Describe a Cornish boiler.

A.—A cylindrical flue of a diameter sufficient to contain the furnace extends lengthwise through another cylinder of considerably larger diameter, the water being in the space between the two and covering the smaller cylinder (see Figs. 1 and 2). The furnace is placed in one end of the internal flue, the products of combustion passing backward through this flue, dividing and returning along the sides, and passing back beneath to the uptake.

Q. 6—How does the Lancashire boiler differ from the Cornish?

A—In the use of two furnace flues instead of one, as shown in Fig. 3.

Q. 7—Describe a multiflue boiler.

A.—This is simply an extension of the same idea, there being three or more flues.

Q. 8—Describe a Galloway boiler.

A.—The two furnaces of a Lancashire boiler are merged, immediately beyond the fire bridge, into one flue of large size as shown in Fig. 4 containing an arrangement of radial cone tubes which strengthen the construction, increase the heating surface, and promote circulation. These are known as "Galloway tubes," and are frequently used in boilers of the Cornish and Lancashire types. The gases after passing backward through the large flue are divided and returned in side flues beneath and in contact with the main shell, as in the previous types.

Q. 9—What are the limiting dimensions of furnace tubes?

A.—Furnaces should not be less than 36 inches nor more than 48 inches in diameter unless under exceptional circumstances.

Q. 10—How should the number of furnaces be proportioned to the diameter of the shell?

A.—Boilers up to 9 feet in diameter may be made with one furnace, up to 13 feet 6 inches with two furnaces, up to 15 feet with three furnaces; beyond that diameter four furnaces are necessary, to avoid too great length of grate. The boilers are frequently made double-ended with a central dividing water leg, in which case the above number of flues may be used in each end of the shell.

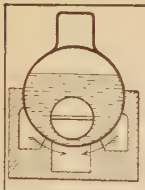
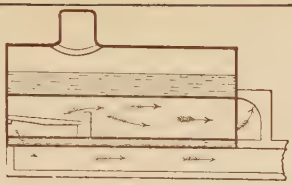


FIG. 1



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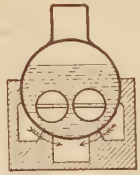

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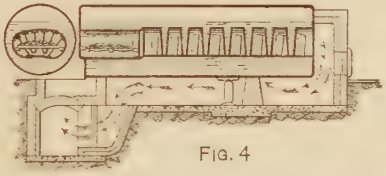

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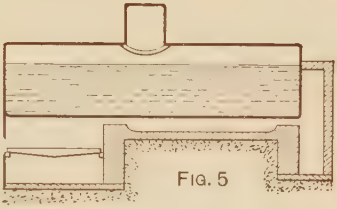

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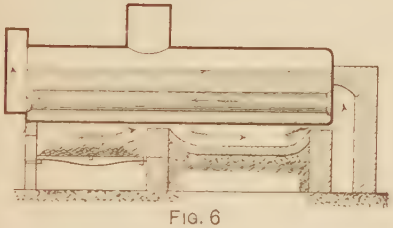

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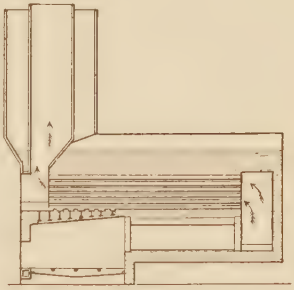


FIG. 7

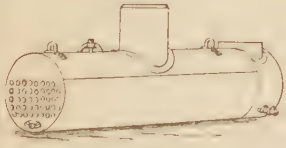


FIG. 8

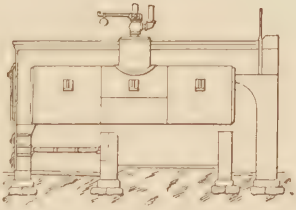


FIG. 9

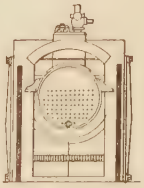


FIG. 10

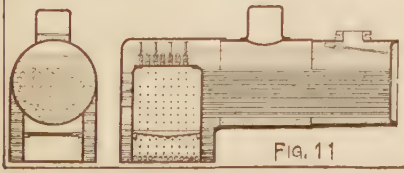


FIG. 11

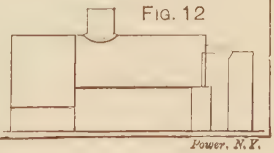


FIG. 12

Power, N.Y.

Q. 11 —Describe a plain cylinder boiler.

A.—This is represented in Fig. 5 and consists of a plain tube ranging from 26 to 40 inches in diameter and from 30 to 40 feet in length, closed at the ends by heads often of cast iron, and usually fitted with a steam drum. It is set in brick work, with the furnace beneath the shell at one end, the gases passing under the boiler its entire length and to the chimney from the back connection

Q. 12 —What are its advantages?

A.—Simplicity and cheapness of construction, ease of cleaning, and freedom from recesses where impurities can accumulate, particularly fitting it for use with very bad water.

Q. 13 —What disadvantages does it possess?

A.—It occupies a large amount of space for the power developed, and if made long enough to absorb the heat of the gases is subject to severe strains from unequal expansion; it also carries a large body of water in proportion to the heating surface, and is consequently slow steaming.

Q. 14 —What is a cylindrical return flue boiler?

A.—A plain cylinder boiler with one or more flues extending through it from end to end as shown in Fig. 6. The furnace is under one end, as in the plain cylinder boiler, but the gases, instead of passing to the stack after having traversed the length of the boiler are returned through the flues to an uptake at the front end.

Q. 15 —What advantages does the flue add to the boiler?

A.—Strength, heating surface, and a reduced volume of water.

Q. 16 —Describe the flue and return tube boiler.

A.—This is shown in Fig. 7. The fire is built in the flue or flues, and returns through the tubes to the uptake. The one shown in the cut is one of a pair arranged to discharge into a common uptake.

Q. 17 —What is the difference between flues and tubes?

A.—More in degree than in kind. When flues four inches or smaller are used, they are called tubes, and the use of a sufficiently greater number to make up the required area for the passage of the gases leads to the horizontal tubular boiler in general use.

Q. 18—Describe the horizontal tubular boiler.

A.—This is shown in Figs. 8, 9 and 10. It is similar to the return flue boiler, the only point of difference being that tubes are employed instead of flues.

Q. 19—What is the particularly good feature of the boiler shown in Fig. 8?

A.—A single large sheet is employed to form more than two-thirds of the shell. This prevents the fire from reaching the seam when the boiler is set.

Q. 20—What can you say of the advantages of the horizontal tubular boiler?

A.—It is simple in form, easy of construction, requires bracing only on the flat heads (which are in great part sustained by the tubes), generates a reasonably large amount of steam for the space occupied, is not difficult to keep clean, with passable water, and may be proportioned to give a very high efficiency.

Q. 21—Describe a fire-box boiler.

A.—The end sheet of a cylindrical shell is continued straight downward upon the sides, and inclosed to form a structure rectangular in its lower portion and conforming to the curvature of the cylinder at the top as shown in Fig. 11. Inside the rectangular portion is secured a fire-box, separated from the sides by water spaces called "water legs," and having its top, which is called the "crown sheet," above the center of the cylindrical portion. An opening is formed in both sheets at the front end for the door frame, and the back end of the inside fire-box forms a tube sheet for numerous small tubes, which convey the products of combustion to the smoke-box in front.

Q. 22—What are the principal advantages of this construction?

A.—It requires no brick setting, is portable and self-contained, and may be made to generate a large amount of steam for the weight and space occupied. The cost of setting is small, and the exterior is easily accessible for inspection and repairs. These features may be seen by reference to Fig. 12, which shows the boiler as installed.

Q. 23—What are its particular disadvantages?

A.—The necessity of bracing and staying the extensive flat surfaces, and the difficulty of circulation and tendency to deposit in the water leg.

Q. 24.—How is a vertical tubular boiler ordinarily made?

A.—A cylindrical fire-box is set into the lower end of a vertical cylindrical shell, as shown in Fig. 13, the space between forming an annular water-leg. The top of the fire-box serves as a tube sheet for numerous tubes, which extend through the closed top of the outside shell and convey away the products of combustion. The upper portion of the tubes is surrounded only by steam. Another type is shown in Fig. 17.

Q. 25.—What advantages has this type?

A.—Minimum floor-space, portability, low cost of setting up, and a wide allowable variation in water level.

Q. 26.—What are its disadvantages?

A.—Liability to leakage in the exposed upper ends of the tubes, and deposits in the water-legs. Also, in the smaller sizes, inefficiency from lack of heating surface. This latter fault can be corrected by making the boiler very tall, and some of the larger constructions of vertical boilers are remarkably efficient.

Q. 27.—What is a water tube boiler?

A.—A boiler in which instead of the fire passing through tubes surrounded by water, as in the preceding types, the water is contained in tubes surrounded by fire.

Q. 28.—Describe the general construction.

A.—A bank of tubes is placed on an incline above and behind the furnace, as shown in Fig. 14, which represents the Babcock & Wilcox boiler. The tube ends are connected at front and back by headers or receptacles, differing in the several constructions. A rapid upward circulation is generated by the application of heat, the steam and heated water being delivered from the front connections to a drum above and replaced in the tubes by the feed and downward flow of water from the drum into the back connections.

Q. 29.—What are the distinctive advantages of this type?

A.—Safety from disastrous explosions, lightness and compactness, quick steaming qualities, ease of transportation, and (from the effective character of its heating surface) high efficiency with small space.

Q. 30.—What is a sectional boiler?

A.—A boiler made up of a number of sections or units. Water-tube boilers are usually considered as of this class, but

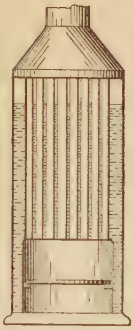


FIG. 13

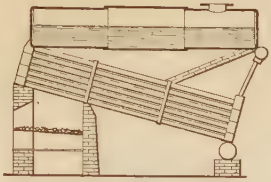


FIG. 14

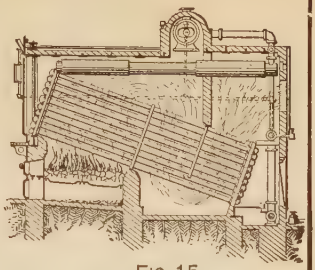


FIG. 15

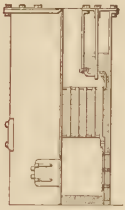


FIG. 17

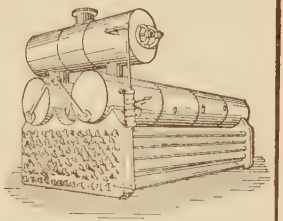


FIG. 18

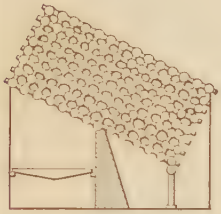


FIG. 16

FIG. 20

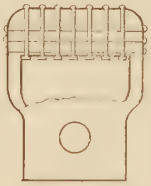


FIG. 21

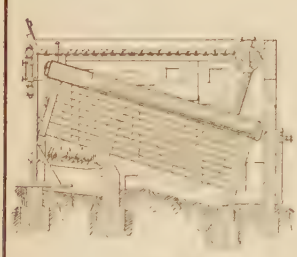


FIG. 19

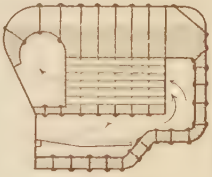


FIG. 23

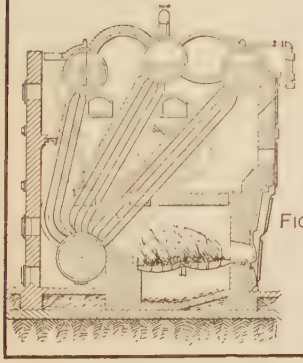
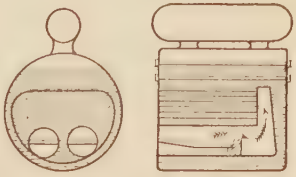


FIG. 22

FIG. 24



Power, N.Y.

a more distinctive type, consisting of spheres of cast iron or steel about 8 inches in diameter and connected by narrow necks, is shown in the Fig. 16, which shows the Harrison boiler. These spheres are fitted with faced joints, and secured by long bolts passing from end to end of each row, so proportioned that a pressure less than that required to burst one of the units would stretch the bolt and allow each joint to leak and relieve the pressure.

Q. 31 —Are there other forms of water tube boilers?

A.—Yes; various arrangements and combinations of coils, tubes, and sections.

Q. 32 —What are their general characteristic advantages?

A.—Quick steaming, small weight and space required,—in general, the advantages of the water tube type in a greater degree than the simpler constructions.

Q. 33 —What are some of the disadvantages to which the type is liable?

A.—Difficulty of keeping the numerous joints tight, and of cleaning the bent tube of small diameter; and burning out from imperfect circulation.

Q. 34 —Describe the Root boiler.

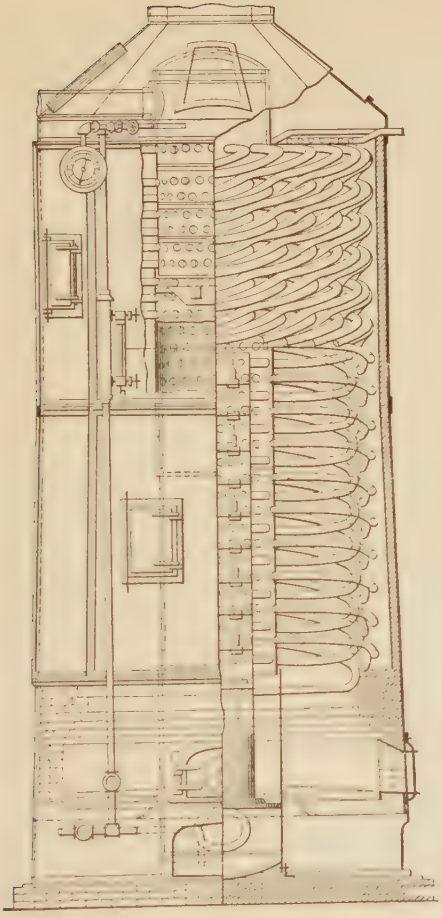
A.—This is shown in Fig. 15, and is of the sectional water-tube type. The tubes are completely submerged, the water level being in the longitudinal drums of small diameter, of which there is one for every section. These are connected at their rear ends by a collecting pipe which shows at the right hand lower corner of the cut; and from this pipe steam is led to the cross drum.

Q. 35 —Describe the Campbell & Zell boiler.

A.—The longitudinal cylinder is directly above the tubes, as shown in Fig. 19, and inclined at the same angle instead of being horizontal as in the other types, and the water line is just below the front end as shown. Steam is conveyed from the space thus formed to a cross drum situated at the back end.

Q. 36 —Describe the Heine boiler.

A.—The tubes are expanded as shown in Fig. 18, into large plate steel water legs, depending from the front and rear of the drum. The leg is stayed in the usual manner, and hand holes are provided opposite each tube. Two drums are usually



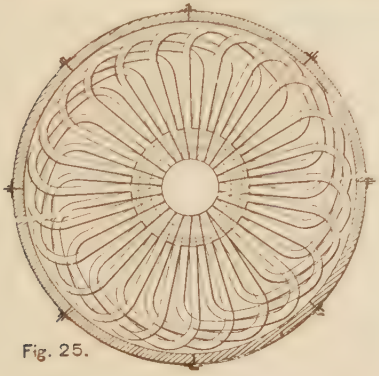


Fig. 25.

employed, delivering into a cross drum as shown in the cut. The boiler is constructed entirely of tubes and plates, no cast metal being employed.

Q. 37.—Describe the Stirling boiler.

A.—In this boiler, which is represented in Fig. 22, the tubes are bent, but only a trifle. The water is fed into the rear drum, passes downward through the rear tubes, which are exposed to gases just leaving the boiler, and then upward through the front tubes and downward through the central tubes.

Q. 38.—Describe the Climax boiler.

A.—This consists of a vertical shell, Fig. 25, into which are expanded tubes of the form shown in the plan, one end of each tube entering the shell at a point considerably higher than the other, as shown in the elevation. In the lower portion of the vertical cylinder is another cylinder, of smaller diameter, into which the feed water is introduced and from which it passes through tubes entering the lower ends of the loops before described. The

water, being heated in the loop, is surrounded by heated gases, and carried through the tube and discharged from its higher end into the annular space between the inner and outer upright cylinders, the steam finding its way to the steam space. By the interposition of a number of diaphragms the steam is then made to pass through the loops in the upper part of the boiler on its way out, in order to thoroughly dry or even superheat it. The water, being fed into the central drum, deposits its sediment in the quiet dead-end beneath the grate level, where provision is made for blowing off and cleaning.

Q. 39—What is the common type of locomotive boiler?

A.—The fire-box boiler.

Q. 40—What two varieties of the locomotive firebox boiler are there?

A.—The Belpaire and the Wagon Top.

Q. 41—What is the difference between them?

A.—The principal difference is in the shape of the boiler over the firebox and the method of staying, as shown in Figs. 20 and 21, which represent the Wagon Top and Belpaire respectively.

Q. 42—Describe the Wotten boiler.

A.—The distinguishing feature is the firebox which is wide and shallow, and has a combustion chamber with a brick bridge across the firebox end.

Q. 43—How is a marine tubular boiler made?

A.—As shown in Fig. 23, the furnaces being arranged to deliver the products of combustion directly into the back connection, the gases passing forward again through numerous small tubes.

Q. 44—Describe the construction of the Drum or Scotch boiler.

A.—The general appearance is shown in Fig. 24. The shell is cylindrical, and generally from 8 to 16 feet in diameter. The furnaces are set in heavy tubes, the gases being discharged into a back connection, whence they are taken to an uptake in front through a number of small tubes.

Q. 45—What types of boilers are not adapted to high pressure?

A.—Those in which there are many flat surfaces, requiring a complicated system of bracing and staying.

SECTION II.

Boiler Setting.

Q. 46—Why is the setting of a boiler a matter of great importance?

A.—Because a boiler setting is subjected to a much greater strain in proportion to the weight supported than is the case with ordinary walls and foundations, on account of the varying degrees of heat to which the walls are exposed.

Q. 47—How does this affect the foundation?

A.—The foundations must be unusually heavy, as varying degrees of strain are thrown upon them, and the least settlement is dangerous, as the walls become cracked and the pipe connections are thereby strained.

Q. 48—What is a good setting for a horizontal tubular boiler?

A.—That shown in Figs. 26, 27, 28 and 29, which is the setting known as the projecting front and is recommended by the Hartford Steam Boiler Inspection and Insurance Company.

Q. 49—What advantages has this setting over the flush front?

A.—It costs less for repairs and no more to put in than the flush front, while it is also of better appearance.

Q. 50—What is the commonest defect of boilers set with flush front?

A.—The burning and breaking off of the shell on the lower side just forward of the front tube sheet.

Q. 51—How is this caused?

A.—By the fire brick arch over the furnace door becoming loose and falling down, thus exposing the dry portion of the boiler to the direct action of the intense heat of the furnace fire.

Q. 52—How much should the front project?
A.—From 12 to 16 inches according to the size of the boiler. See Table I, column B.

Q. 53—How deep should the excavation be made for the foundation in favorable earth?
A.—Not less than three feet.

Q. 54—What shape is the excavation in such a case?
A.—Trenches, where the walls will stand.

Q. 55—What should be done if the earth is soft?

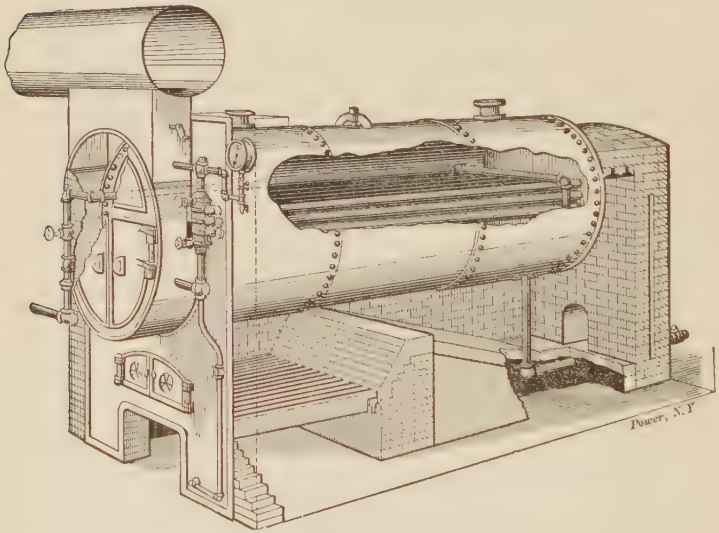


FIG. 26

A.—The excavation should cover the entire area to be occupied by the setting and the pit filled with sand, gravel or broken stone and concrete in which there is a good proportion of cement, and the foundation started on this bed.

Q. 56—What should be done in case quicksand should be encountered?
A.—Put into the excavation not less than two feet of gravel, well rammed.

Q. 57—Should wooden platforms ever be used?

SETTING FOR
HORIZONTAL TUBULAR BOILERS
DESIGNED BY
THE HARTFORD STEAM BOILER INSP. & INS. CO.

See Table for Dimensions
Represented by Letters.

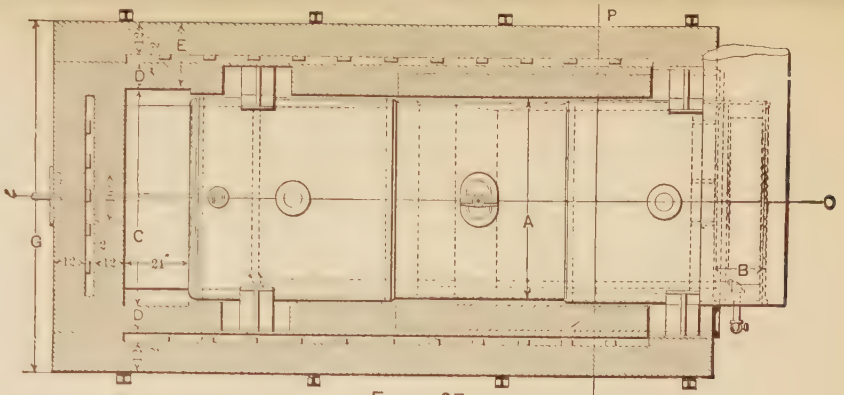
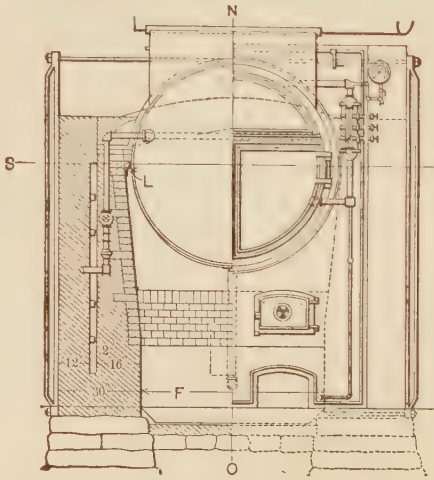


FIGURE 27
HORIZONTAL SECTION AT S-T, FIGS. 28 & 29

FIGURE 29.

TRANSVERSE SECTION AT P-R, FIGS. 27 & 28

FRONT ELEVATION



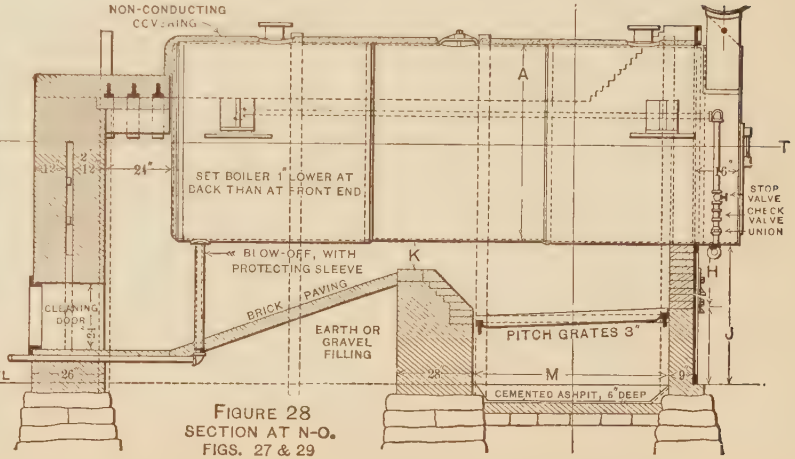


FIGURE 28
SECTION AT N-O.
FIGS. 27 & 29

A.—Not unless the locality is so wet that the platforms will always be submerged.

Q. 58—How should the footing courses of the foundation be laid?

A.—They should be of large, flat stones, carefully bedded to prevent rocking, and laid in cement.

Q. 59—What about the next two or three courses?

A.—They should also be of large stones, laid so as to break joints and distribute the weight as evenly as possible.

TABLE I.

MEASUREMENTS FOR THE SETTING OF HORIZONTAL TUBULAR BOILERS.

A Diameter of Boiler	B Curtain Sheet.	C Width of Flame Bed.	D Inside Side Walls at Center of Boiler.	E Total Thickness of Side Walls at Center Line of Boiler.	F Width of Furnace.	G Width of Setting.	H Top of Front End of Grate to Bottom of Boiler.	I Top of Front End of Grate to Floor Level.	J Bottom of Boiler to Floor Level.	K Bottom of Boiler to Top of Bridge Wall.	L Air Space at Sides of Boiler at Center Line.	M Length of Grate Recommended.	A Diameter of Boiler.
48	12	56	9	23	42	102	24	24	48	9	4	48	48
50	14	58	9	23	44	104	24	24	48	9	4	50	50
52	14	60	9	23	46	106	24	24	48	9	4	52	52
54	14	62	9	23	48	108	24	24	48	9	4	54	54
56	14	64	9	23	50	110	24	24	48	9	4	56	56
58	14	66	9	23	52	112	24	24	48	9	4	58	58
60	14	68	9	23	54	114	24	24	48	9	4	60	60
62	16	68	10	24	56	116	28	24	52	10	3	62	62
64	16	70	10	24	58	118	28	24	52	10	3	64	64
66	16	72	10	24	60	120	28	24	52	10	3	66	66
68	16	74	10	24	62	122	28	24	52	10	3	68	68
70	16	76	10	24	64	124	28	24	52	10	3	70	70
72	16	78	10	24	66	126	28	24	52	10	3	72	72

Q. 60—What should be done above this point?

A.—The walls from a distance of not less than 4 inches below the boiler room floor or ash pit, as the case may be, should be of hard burned brick.

Q. 61—How should the rear and side walls be made?

A.—Double, with a two inch air space between them.

Q. 62—What is the object of these double walls?

A.—To lessen the liability of leakage of cold air through the walls of the setting.

Q. 63—Should the double walls be tied together?

A.—No, but bricks should project from the outer wall and just touch the inner one. This allows the inner wall to expand without affecting the outer or retaining wall.

Q. 64—How thick should the outer wall be made?

A.—12 inches, both sides and rear, in every case.

Q. 65—What distance should be allowed between the boiler and the inner rear wall?

A.—24 inches.

Q. 66—How thick should the inner rear wall be made?

A.—12 inches in every case.

Q. 67—How should the inner side walls be made?

A.—With a batter, as shown in the end view.

Q. 68—What is the object of this batter?

A.—It gives great stability to the wall and affords a better opportunity for the circulation of the heated gases. As shown in the cut, with a space at the sides of the boilers, it affords a chance to make inspections and repairs of the shell, and also facilitates the removal of soot and ashes; and these, in addition, do not form as readily as when the walls are straight.

Q. 69—Where does this batter begin?

A.—Just above the grate.

Q. 70—What is the thickness of the inner wall at that point?

A.—16 inches in every case.

Q. 71—What is the thickness of the wall at the center line of the boiler?

A.—9 or 10 inches, according to the size of the boiler. See Table I, column D.

Q. 72—How are the walls tied together?

A.—By rods passing from wall to wall across the setting and secured to the top and bottom of ribbed or trussed cast iron plates as shown in the engraving.

Q. 73—Where should the side walls be closed in to the boiler?

A.—At the center line or just above it.

Q. 74—Why are they closed in there?

A.—Because the water level of the boiler is only a short distance above that point, and the fire line must never be above the water line.

Q. 75 —Why is it not permissible to have the fire line above the water line?

A.—Because steam is not a good conductor of heat, and the intense heat if applied to the shell alone is sure to ruin it sooner or later. In addition, the circulation is impeded, and the evaporative capacity is reduced.

Q. 76 —What form of setting is then prohibited?

A.—That in which the flue is carried back along the sides of, or over the shell.

Q. 77 —What trouble usually arises from this setting?

A.—A distortion of the walls occurs, whereby the fire takes a short cut from the furnace up the sides of the boiler, without first passing under the shell and back through the tubes.

Q. 78 —What is the proper thickness for the front wall?

A.—9 inches.

Q. 79 —How should the shell be treated above the closing-in line?

A.—It should be covered over with a non-conducting covering, or arched over with brick. In the latter case two inches should be left between the boiler and the brick.

Q. 80 —How should the back connection be treated?

A.—It should be covered by a brick arch resting on iron bars as shown in cross section in Fig. 28.

Q. 81 —On what do the ends of these bars rest?

A.—On the side walls of the setting.

Q. 82 —How is the rise of the arch determined?

A.—It is made sufficient to render the tubes easily accessible at the back end.

Q. 83 —Of what sort of brick should the arch be made?

A.—Preferably of fire brick, but, if the boiler and grate surface are well proportioned and the boiler not forced, ordinary hard burned bricks will answer.

Q. 84 —How is the closing in of the back end best done?

A.—By carrying the brick work up above the top of the arch even with the upper part of the shell, curving it to con-

form with the curve of the shell, and plastering it over with any of the excellent non-conducting coverings on the market.

Q. 85 —Does the rear end of the boiler touch the arch?

A.—No. A space of 3-4 of an inch should be left so that, as the boiler expands, its movements will not affect the brick-work.

Q. 86 —What can be said of the brick composing the inner face of the walls throughout the setting, except where firebrick are called for?

A.—They should be carefully selected from the lot.

Q. 87 —How should the joints be made for the ordinary brick-work?

A.—They should be laid as thin as possible; not over 1-8 of an inch thick.

Q. 88 —How should the mortar be mixed?

A.—One part of lime, with five or six parts of clean sand, well screened.

Q. 89 —Where are fire-brick required?

A.—The arch of the back-connection should be made of these, and the furnace should be lined with them.

Q. 90 —What is the proper method of laying fire-brick?

A.—Each brick should be dipped in water as it is used, in order that it will not immediately drink up the water from the mortar A thin coat of kaolin or fire-clay is then applied, only enough to fill up the irregularities of the surface and give a solid bearing being employed, so that the bricks are practically in contact with one another when laid in position.

Q. 91 —How should the fire-clay be prepared?

A.—It should be mixed up so thin that it can not well be laid on with a trowel, an iron spoon being preferable.

Q. 92 —What provision is made for repairing or replacing such parts of the furnace lining as burn away?

A.—Every sixth course, beginning with the grates, must be a row of headers well bonded into the masonry behind. This enables the lower courses to be removed, if necessary. Careful attention must be given to this bonding, as otherwise it will be necessary to rebuild the entire wall when repairing the lower courses.

Q. 93 —How should the grates under a horizontal tubular boiler be set?

A.—Inclined toward the back of the furnace, and 3 inches lower at the rear than at the front.

Q. 94—What is the object of setting the grate on an incline?

A.—It gives a thicker layer of coal at the rear end, thus promoting a uniformity of combustion; as, with a uniform layer of coal the air will naturally pass through more freely at the rear end. In addition, the pitch makes slicing and firing easier.

Q. 95—How wide should the grate be?

A.—Six inches less than the diameter of the boiler. See Table I, column F.

Q. 96—What is a good length of grate?

A.—Equal to the diameter of the boiler. If the boiler is an odd size, choose the length of grate bar nearest to the diameter.

Q. 97—How do grate-bars vary in length?

A.—By six inches. That is, they will come at 3 feet, 3 1-2 and so on.

Q. 98—What factors modify the length of the grate-bar?

A.—The kind of fuel used, rate of combustion and amount of heating surface in the boiler.

Q. 99—What are the requirements of a grate-bar?

A.—It must furnish a supporting surface of sufficient fineness to retain the fuel used upon it with the least obstruction to the passage of air; and it must retain its shape and not melt, warp, or burn out.

Q. 100—What are the advantages of shaking grates?

A.—They allow the fire to be kept clean without frequent opening of the furnace doors and consequent cooling down of the furnace, and in a much easier manner than by the use of tools.

Q. 101—What should be the distance between the bottom of the boiler and the top of the grates at the front end?

A.—The distance should be 24 inches for boilers up to and including 60 inches, and from 62 to 72 it should be 28 inches. See Table I, column H.

Q. 102—What is the correct distance from the top of the front end of the grates to the floor level?

A.—24 inches in every case.

Q. 103—What is the office of the bridge wall?

A.—To form a back to the furnace and retain the coal upon the grate.

Q. 104—Should it be curved across the top to conform the curvature of the shell?

A.—No. It should be built straight across.

Q. 105—How thick should the bridge wall be made?
A.—28 inches.

Q. 106—How far should the top of the bridge wall be below the shell of the boiler?
A.—9 or 10 inches, according to the size of the boiler. See Table I, column K.

Q. 107—What shape should the bridge wall be made?
A.—It should be beveled off at an angle of 45 degrees, commencing the bevel 4 inches above the grate.

Q. 108—What is the object of sloping off the bridge wall in this way?
A.—In order to facilitate the removal of clinkers and furnish an ample and natural passage for the flame.

Q. 109—How should the ash-pit be made?
A.—About 6 inches deep, with sides sloping at an angle of 45 degrees, with a good layer of cement over the bottom and up the sides to keep it water tight.

Q. 110—How should the ash-pit be kept when running?
A.—Full of water.

Q. 111—What good does this do?
A.—It aids greatly in keeping the grate bars from warping, as the pit is always kept cool by the quenching of the coal and hot ashes which drop through. In addition, the vapor always rising seems to aid in combustion by keeping the fire decidedly cleaner on the under side.

Q. 112—How is the space back of the bridge wall treated?
A.—An incline is made by filling in with earth; and this is paved over with bricks, as shown in Fig. 28.

Q. 113—What name is given to this filled in portion?
A.—It is called the flame-bed.

Q. 114—How high should the bottom of the flame-bed be above the floor level?
A.—8 inches.

Q. 115—What is the advantage of constructing the combustion chamber in this way?
A.—If a cleaning door is placed in the rear wall it makes it an easy matter to hoe out the ashes from the back connection at any time without waiting for the boiler to cool.

Q. 116—What size should the cleaning door be made?
A.—24×16 inches, as shown in Figs. 27 and 28.

Q. 117—How is a boiler ordinarily mounted on the setting?
A.—Plates are placed on the side walls of the setting. Cast iron brackets or lugs are riveted, not bolted, on the sides of the boiler, and these lugs rest upon the plates.

Q. 118—How many lugs are employed?
A.—Four. Two on each side of the boiler.

Q. 119—What provision is made for the expansion of the boiler?
A.—The back lug does not rest directly upon the plate but upon iron rolls.

Q. 120—Should the boiler be set perfectly level?
A.—No. The rear end should be set one inch lower than the front end.

Q. 121—What is the object of this?
A.—To bring the blow-off pipe which is located at the rear at the lowest point in the boiler.

Q. 122—What is meant by a "battery" of boilers?
A.—Two or more boilers with a common setting, arranged to deliver steam to a common steam-pipe.

Q. 123—What additions or changes are necessary in the brickwork in setting a battery of horizontal tubular boilers?
A.—The wall dividing the boilers is made double, with a two-inch air-space. These walls are not tied together, but have projecting bricks as in the double walls for a single boiler. Each of these walls is made of the thickness given in Table I, for inside side-walls of single boilers.

Q. 124—How many bricks are required for the setting of horizontal tubular boilers?
A.—The accompanying table, No. II, prepared by the Hartford company, shows the number of ordinary brick and fire-brick required for various diameters and lengths of boilers, and also furnishes a means of determining the brick required for any other length.

Q. 125—How many bricks will be required to set a 54-inch boiler with 15-foot tubes, overhanging front?
A.—The table gives the number at once. 16,700 common brick and 886 fire-brick.

Q. 126—How many bricks will be required to set a flush front boiler, 72 inches in diameter, with 20-foot tubes?
A.—The table gives 24,000 common bricks for a 72-inch boiler with 18-foot tubes. The boiler given has tubes 2 feet longer than this. In the sixth column we find that 860 bricks

must be added for each lineal foot in excess of 18, so that there must be added 860×2=1,720 bricks, giving a total of 25,720 common bricks. The necessary number of fire-bricks, 1,400, can be taken direct from the table.

Q. 127—How many bricks will be required for a battery of 3 boilers, 60-inch, 15-foot tubes, projecting front?

(1). The number of fire-brick for one such boiler is 950, so the three boilers will require 3×950=2,850 fire-brick.

(2). The number of common brick required for one such boiler, with 16-foot tubes, is 18,200. From this must be deducted 760, from the sixth column of the table, as the given boiler is one foot shorter than the tubular boiler; giving 18,200—760=17,440 common bricks for the first boiler.

(3). For each of the other two boilers there would be required 9,700 common bricks, if the tubes were 16 feet long.

TABLE II.

BRICKS REQUIRED FOR BOILER SETTING.

Diameter of Boiler.	Length of Tubes.	Kind of Front.	Number of Common Brick.	Number of Fire Brick.	Additional Number of Brick per Foot of Length.	Number of Common Brick for Each Boiler After the First.	Additional Number of Brick for Each Boiler After the First, per Lineal Foot.	Diameter of Boiler.
36	10	Flush Overhanging	11,700 11,000	564 525	650	6,300 5,900	350	36
42	12	Flush Overhanging	13,700 13,000	654 629	680	7,400 7,000	360	42
48	15	Flush Overhanging	16,700 16,000	850 816	710	8,900 8,500	370	48
54	15	Flush Overhanging	17,600 16,700	990 886	730	9,400 8,900	380	54
60	16	Flush Overhanging	19,100 18,200	1,140 950	760	10,200 9,700	400	60
66	16	Flush Overhanging	21,900 20,600	1,290 1,080	830	11,900 11,300	450	66
72	18	Flush Overhanging	24,000 23,000	1,400 1,150	860	13,400 12,800	460	72

But, as they are 1 foot shorter, 400, found in the last column, must be deducted, giving 9,300 for each of the last two, or 9,300 × 2 = 18,600 common bricks.

(4). The total number of common bricks is therefore 18,600 + 17,440 = 36,040.

Q. 128.—Does this table include brick for covering the boiler in on top?

A.—No, it simply provides for the main setting.

SECTION III.

Boiler Fittings and Attachments.

Q. 129—How should the feed-water be introduced into the boiler when the water is clear?

A.—The feed-pipe enters the front connection just above the level of the tubes at the left-hand side. It then turns and enters the boiler just inside the flange of the head, and passes down the boiler on the inside, nearly to the back end. Then it crosses over to the right-hand side and discharges downward between the tubes and shell. This is the style recommended by the Hartford Steam Boiler Inspection and Insurance Co., and is shown very clearly in Figs. 26, 27, 28 and 29.

Q. 130—What is the advantage of this method?

A.—The feed becomes heated almost to the temperature of the water in the boiler before it is discharged, thus avoiding the dangerous effects that are produced when the shell is chilled by cold water.

Q. 131—When is the top-feed preferable?

A.—When the water is muddy.

Q. 132—How may that feed be arranged?

A.—As shown in Fig. 30, taken from the Locomotive. The pipe is the same size as the feed-line. The spray plates are made of iron, 10 inches in diameter, and hammered to a convex shape. The short upright pipes shown in the cut pass through the plates, and are secured by lock-nuts as shown. The water bubbles to the top of the plates and runs off as it would from an umbrella. The trap form of the arrangement prevents steam from entering the feed line and causing snapping or pounding noises from condensation.

Q. 133 —What size are the branches?

A.—The piping used is of the same diameter as the feed-line. The rest of the dimensions are given in the cut.

Q. 134 —What is the correct diameter of feed pipes?

A.—On boilers from 36 to 40 inches in diameter the pipe should be at least 1 inch. From 42 to 54 the diameter should be at least 1 1-4 inches, and for boilers over 54 inches the pipe must be at least 1 1-2 inches. To these it is well to add one size for bad water.

Q. 135 —Where should the blow-off be located?

A.—At the rear of the boiler, as shown in Figs. 26, 27, 28 and 29.

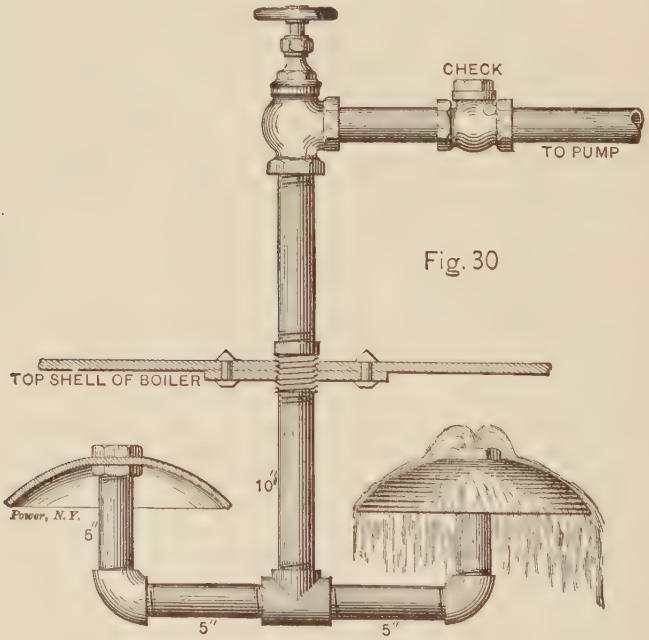


Fig. 30

Q. 136 —How should the shell be treated at the point where blow-off leaves the boiler?

A.—It is very important that it should be re-enforced.

Q. 137 —How is the blow-off protected?

A.—It is encased in a protective sleeve of some kind, as shown by the dotted lines in Fig. 28. A piece of iron or soil pipe slipped over the blow-off will answer.

Q. 138—What can you say of the location of bends in the blow-off pipe?

A.—There should be none in the combustion chamber, where the flames can get at them.

Q. 139—Where should the outlet for steam be located upon a boiler?

A.—On top and near the rear end.

Q. 140—Why is the rear end better than the front?

A.—Because the water is in violent motion at the front end immediately over the fire, and drier steam would be secured by taking it from the quieter portion of the steam space.

Q. 141—What kind of piping should be used throughout, except where otherwise specified?

A.—Wrought iron.

Q. 142—What is the object of the blow-off?

A.—To afford an opportunity to let the water out of the boiler, in order to remove the sediment which accumulates.

Q. 143—How much sediment would be deposited in a 100 horse-power boiler in 30 days, working at its rated capacity 10 hours per day, with water having 21 grains of solid matter to the gallon, if the blow-off were not used?

A.—Assuming 4 gallons per hour per horse-power, 100 horse-power would use 400 gallons per hour, or $400 \times 300 = 120{,}000$ gallons in the 30 days. This would contain $21 \times 120{,}000 = 2{,}520{,}000$ grains, which as there are 7,000 grains to the pound, would equal $2{,}520{,}000 \div 7{,}000 = 360$ pounds.

Q. 144—Under what pressure should a boiler be blown out dry?

A.—The best practice where the sewer or drain is below the boiler level so that the water will run off naturally is to let the boiler cool off entirely, and allow the water to drain off by gravity, opening the cocks and safety-valve to allow the air to enter. The loose sediment is then left in the form of a soft mud easily removed by washing with a hose; whereas if the boiler and its surrounding brickwork were hot the mud would be baked on and not easily removed.

Q. 145—Will not some of the sediment attach itself to the surfaces and form a scale while the boiler is in use?

A.—Yes; but this may be prevented by the use of substances which keep the sediment in solution and do not allow the particles to adhere to each other.

Q. 146—What is the best valve to use upon the blow-off?

A.—A plug cock having an opening equal in width to the diameter of the pipe, the tight closing of which is less likely to be interfered with by a chance piece of scale than a globe or gate-valve.

Q. 147—How should the blow-off be used?

A.—It should be opened for a short time once or oftener each day, blowing out such of the sediment as will readily escape. A good time to do this is in the morning before the settled sediment becomes too much stirred up by the circulation. At intervals more or less frequent, according to the character of the water and the amount of work done, the boiler should be entirely emptied of its water and washed and scraped clean of sediment and scale.

Q. 148—What valves are used on the feed-pipe?

A.—A stop-valve and a check-valve, placed as shown in Fig. 28.

Q. 149—What is the object of the stop-valve?

A.—To control the admission of feed-water.

Q. 150—What is the object of the check-valve?

A.—To prevent the water in the boiler from backing out.

Q. 151—What is the object of the union shown in the cut?

A.—It enables the valves to be easily removed or repaired without disturbing the rest of the piping.

Q. 152—What means have you of knowing the height of water in a boiler?

A.—The gage-glass and the try-cocks.

Q. 153—How should the try-cocks be located?

A.—The lower cock should be three inches above the top row of tubes or the surface first to be exposed by lack of water; preferably in the boiler itself, but allowably in a water column or "combination" carrying both glass-gage and try-cocks.

Q. 154—What is the United States marine law regarding gage-cocks?

A.—"All steamers having one or two boilers shall have three suitable gage-cocks in each boiler. Those having three or more boilers in battery shall have three in each outside boiler and two in each remaining boiler in the battery; and the middle gage-cocks in all boilers shall not be less than four inches above the top of the flues, tubes or crown of the fire-box."

Q. 155—How far apart should they be?

A.—For a boiler five feet in diameter, 4 inches; 3 or 3 1-2 for smaller diameters.

Q. 156.—How should a glass gage or combination be connected?

A.—As directly as possible to the boiler and with 1 1-4 inch solid drawn brass tubing, pipe size and thread. Plugged crosses should be used at corners instead of elbows, so that access may be had to the pipes for cleaning. A ground brass union is placed in the water connection, so that the column may be readily put together and taken apart. The general appearance is shown in Fig. 31.

Q. 157.—What provision is made to prevent the accumulation of sediment in the water column?

A.—A half or three-quarter-inch drain-pipe runs from the double tee in the water connection, thus making it possible to blow off the water column.

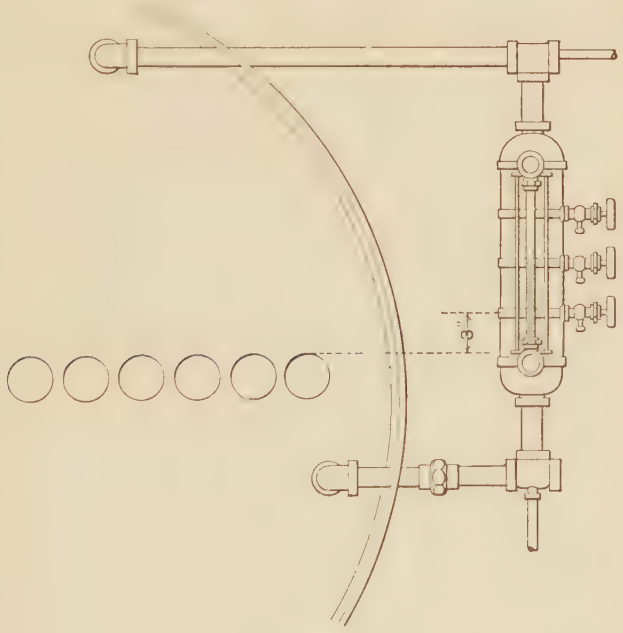


FIG. 31.

Q. 158.—What are the chief points to be considered in the connection of steam-gages?

A.—They should be so placed as not to be liable to injury from the heat of the steam, nor from the heat radiated from the boiler front or from the uptake; and provision should be made for removing the gage while the boiler is in service, in case it should be desirable to do so, and also for blowing out the piping without disturbing the gage.

Q. 159.—What means are employed to protect the spring from injury through direct contact with the steam?

A.—A form of siphon is interposed between the gage and the boiler, in which water of condensation can collect and serve as a protection.

Q. 160.—Describe the manner in which the gage should be connected.

A.—The form of connection shown in Fig. 32 is that advised by the Hartford Company, and it works well in practice. It is built up of nipples and fittings, and the gage is provided with a stop-cock and a ground union. There is also a small cock at the lowest part of the siphon, for blowing out such sediment as may lodge in the bend. If the boiler is out of service the water may be discharged from the siphon by merely opening the air cock; but if it is desired to blow the pipes out while the boiler is in service, the stop cock in the vertical pipe should be closed first, so that the gage may not be injured. After the siphon has been blown out the gage should not be again connected to the boiler until it is judged that a sufficient amount of water of condensation has collected in the siphon to take the place of that which was blown.

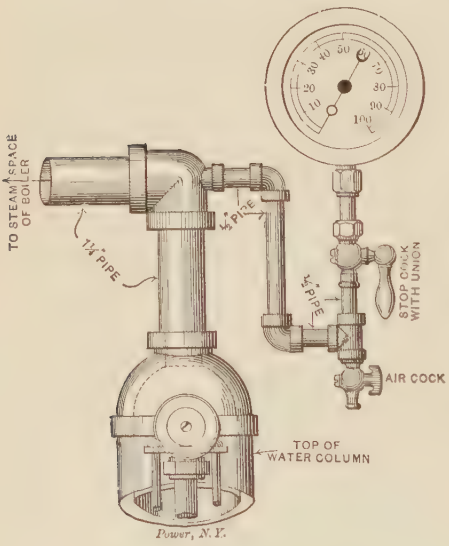


FIG. 32.

Q. 161.—What appliances are provided to guard against accidents from the low water?

A.—Alarms which call attention to the shortage of water by blowing a whistle or ringing a bell, and plugs filled with a

metal which fuses at a comparatively low temperature, are placed in the heating surface liable to be first overheated from lack of water.

Q. 162—Are fusible plugs required by law?

A.—Yes; in Massachusetts, in some of the larger cities of other States, and upon marine boilers under the jurisdiction of the United States Board of Supervising Inspectors.

Q. 163—What is the United States marine law relating to fusible plugs?

A.—"All steamers shall have inserted in their boilers plugs of Banca tin at least one-half inch in diameter at the smallest end of the internal opening, in the following manner, to wit: Cylinder boilers, with flues, shall have one plug inserted in one flue of each boiler, and also one plug inserted in the shell of each boiler from the inside immediately before the fire line, and not less than four feet from the forward end of the boiler. All fire-box boilers shall have one plug inserted in the crown of the back connection or in the highest fire service of the boiler. All upright tubular boilers used for marine purposes shall have a fusible plug inserted in one of the tubes at a point at least two inches below the lower gage-cock, and said plug may be placed in the upper head sheet when deemed advisable by the local inspectors. All fusible plugs, unless otherwise provided, shall have an external diameter not less than that of a one-half-inch gas or steam-pipe screw-tap, except when such plugs shall be used in the tubes of upright boilers plugs may be used with an external diameter of not less than that of an inch gas or steam-pipe screw-tap, said plugs to conform in construction with plugs now authorized to be used by the Board; and it shall be the duty of the inspectors to see that these plugs are filled with Banca tin at each annual inspection."

Q. 164—What can you say of the washout plugs placed in locomotive boilers?

A.—They should be placed in the back head, in a line about two inches above the crown-sheet. These plugs are made of brass and screwed in. Brass expands more than iron or steel and the plugs would crack the back head unless allowance were made. This is done by drilling or coring the plugs to a depth equal to or a little greater than the thickness of the boiler plate.

Q. 165—What would you do in case of low water?

A.—Cover the fire with green coal or damp ashes, partially close the ash-pit doors, leave the furnace door open, and allow the furnace to cool down.

Q. 166—Should the safety-valve be opened?

A.—No; you do not want to let any more steam out of the boiler in this condition than can be avoided.

Q. 167—Then should the engine be stopped or the stop-valve closed to avoid the further escape of steam?

A.—No. The sudden stoppage of the outflow of steam will cause a fall of the water level. The first thing to look out for is to subdue the heat, which is the source from which trouble is to be expected.

Q. 168—Why had the fire better not be drawn or dumped?

A.—This would result momentarily in stirring up an intense heat. The desired cooling can be effected most rapidly by covering the fire and admitting cold air above it.

Q. 169—What about the feed supply?

A.—Leave it alone. If the pump or injector is running, the water level will be recovered gradually as the boiler stops steaming. If the feed is not on, the sudden introduction of water upon overheated surfaces might precipitate disaster, and the feed should not be started until sufficient time has been allowed for such danger to be averted.

Q. 170—How would you determine if the safety-valve upon a boiler was ample?

A.—Close the stop-valve and force the boiler to its utmost capacity. If the safety-valve allows the steam thus generated to escape so that the pressure is not increased above the amount allowed, the valve is sufficient.

Q. 171—What precautions should be taken with the safety-valve?

A.—It should be tried every morning on firing up to see that it is free, and any apparent interference with its freedom of working should receive immediate attention. So much depends upon its proper action that every precaution should be taken to insure its being ready to act when required.

Q. 172—How should the steam-pipes of a battery of boilers be connected?

A.—As shown in Figs. 33 and 34, with a stop valve in each horizontal length, or with an angle stop-valve placed at the top of the riser. This latter construction is preferable.

Q. 173 —What is the object of the horizontal lengths?

A.—They give flexibility to the construction, allow of movement by contraction, expansion, settling, etc., without involving serious strains.

Q. 174 —What should be the height of the risers?

A.—Never less than 3 feet; longer with large batteries.

Q. 175 —What kind of pipe should be used except where otherwise specified?

A.—Wrought iron.

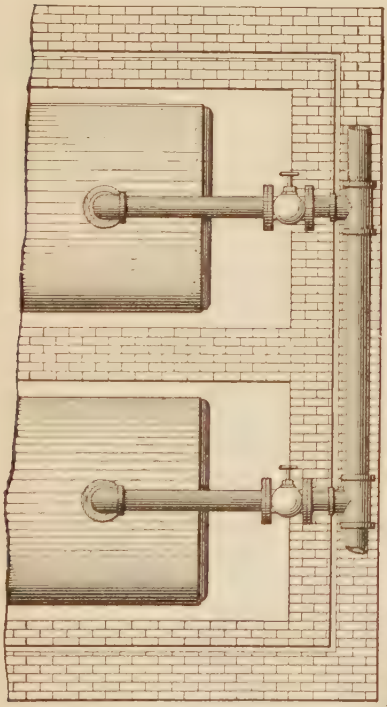


FIG. 33.

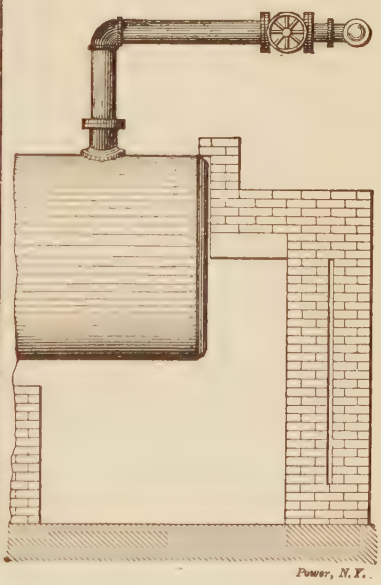


FIG. 34.

Q. 176 —How should the feed connections be made for a battery of boilers?

A.—The feed-pipe should run along the front of the battery and a riser put in to each boiler. Each boiler should have a separate stop and check-valve; the former being to control the admission of feed so that either boiler may be fed separately

and the latter to prevent the water from backing out of either boiler into the other.

Q. 177—Should each boiler in a battery have a separate safety-valve?

A.—Yes, by all means. Many accidents have resulted from a lack of this precaution.

Q. 178—How so?

A.—Suppose two boilers in a battery with a safety valve on No. 1 and none on No. 2. Then suppose No. 1 shut down. There is nothing to relieve excessive pressure in No. 2.

Q. 179—Where are man- and hand-holes located on a horizontal tubular boiler?

A.—There is a man-hole on the top of the second course, and a hand-hole on each of the heads at the lower row of tubes.

Q. 180—There are numerous holes cut in boilers for man- and hand-hole plates, pipe connections and so on. When should these be reinforced?

A.—When they are over six inches in diameter.

Q. 181—What rule should be followed in reinforcing?

A.—Such holes should be reinforced by wrought iron or steel rings of sufficient width and thickness to contain an amount of material equal to that cut from the boiler.

Q. 182—When may these rings be dispensed with?

A.—When the holes are cut in the flat surfaces of boilers and flanged inwardly to a depth of not less than 1.5 inches measuring from the outer surface.

Q. 183—What is a steam-dome or drum employed for?

A.—To act as a reservoir or sort of additional steam-space, from which dry steam can be drawn.

Q. 184—Is it necessary to use one?

A.—No. In most cases it is superfluous.

Q. 185—Where is it placed if used?

A.—On the second or middle course of a three-ring boiler.

Q. 186—What becomes of the man-hole in that case?

A.—It is placed on the last course.

Q. 187—Where is the safety-valve located?

A.—On the front ring usually, the center and back rings being occupied by the man-hole and steam-nozzle.

Q. 188—How should the safety-valve be attached to the boiler?

A.—As directly as possible, and without valves or other possible obstructions between.

Q. 189—How should its discharge be arranged?

A.—Preferably left open so that the steam is discharged into the boiler room. The valve should never blow enough to render this even an inconvenience. If it is piped outside, have the pipes ample for all the discharges to them, separate pipes for each valve, if possible, and without valves or any possibility of obstruction.

Q. 190—How should discharge pipes, if used, be inclined and secured?

A.—Away from the valve so that water will not stand upon it. Pockets where water may stand in the pipe itself should also be avoided. The pipe should be secured against the reaction of the steam when emitted from its open end, which tends to push the pipe with a great deal of force in a direction opposite to that in which the steam is emitted.

SECTION IV.

Bursting Pressure. Riveted Joints. Braced and Stayed Surfaces.

Q. 191.—How is the pressure of steam in an inclosed vessel exerted?

A.—Equally in all directions.

Q. 192.—Suppose a cylinder fitted with a conical piston, as in Fig. 35. Would there be any more tendency for the piston to move, owing to its greater area, than there would be if it were flat?

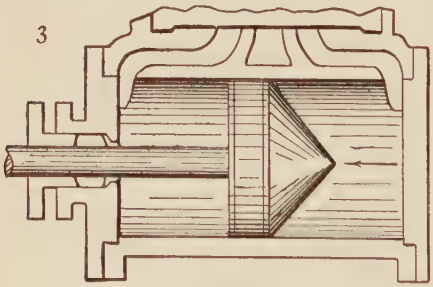


FIG. 35.

A.—No. This will be plain by imagining the piston to be made in steps, as in Fig. 36. The pressure which acts upon the flat surfaces at right angles to the axis of the cylinder is all that tends to move the piston in the direction of that axis, and the sum of those areas is equal to the cross section of the cylinder.

Q. 193.—What about the pressure that acts upon the surfaces parallel to the axis of the cylinder?

A.—That pressure which acts upon the curved surfaces parallel to the axis does not help to move the piston ahead, but would crowd it against the cylinder if it were not balanced by an equal pressure on the opposite side.

Q. 194.—Would this apply in case of a concave piston, as in Fig. 37?

A.—Yes; whatever the shape of the surface acted upon, the force tending to move that surface in any direction will be the pressure per square inch multiplied by the square inches in a projection of the surface upon a plane at right angles to the motion, i. e., the area of the shadow which would be cast by the surface upon a plane at right angles to their motion by parallel rays of light acting in the direction of the pressure.

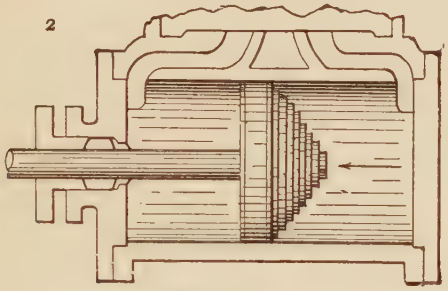


FIG. 36.

Q. 195—How, then, would you determine the force tending to burst a sphere from internal pressure?

A.—By multiplying the pressure per square inch by the number of square inches in a circle having a diameter equal to the internal diameter of the sphere, not by the number of square inches in its concave surface, because the rupture of the shell, as along the line *AD*, Fig. 38, would cause the half of the shell to move away in the direction of the arrow, as though it were a piston in the cylinder *ABCD*, and as we have seen before, its effective area in this direction would be only its projection, which would be the area of a circle of equal diameter. Of course the pressure is acting upon the whole area, but that which acts in another direction, as shown by the small arrow within the globe, brings its greatest force to bear to rupture the shell along the circumference *ab*, and if the pressure is raised to the bursting point the failure will occur along the line where the shell is weakest.

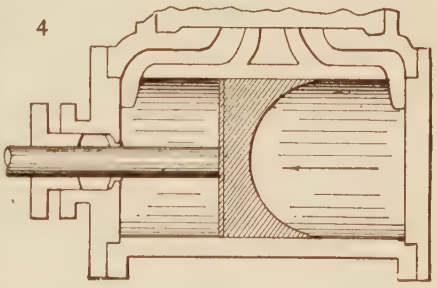


FIG. 37.

Q. 196—In a cylindrical vessel, like a plain cylinder boiler containing steam under pressure, what is the force tending to tear the cylinder apart, in the direction of its diameter as in Fig. 39?

A.—The pressure per square inch multiplied by the *diameter* and length in inches.

Q. 197—Why do you multiply by the diameter rather than the circumference?

A.—Because the pressure in any direction is effective only on the surface at right angles to that direction, which, as in Fig. 39, is the diameter. It is as though each half of the boiler were a concave rectangular piston.

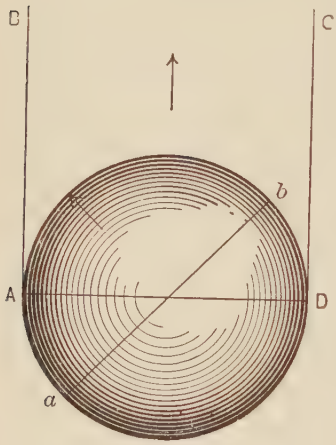


FIG. 38.

Q. 198—What would be the force tending to rupture a cylinder 12 inches in diameter, 2 feet long, with 100 pounds pressure per square inch?

A.—The greatest surface upon which the pressure can be exerted *in any one direction* is $12\times24=288$ square inches; and as there are 100 pounds upon each square inch, the total pressure will be $288\times100=$ 28,800 pounds.

Q. 199—How does the bursting force vary with different diameters?

A.—It varies directly as the diameter. If the diameter is doubled, the bursting force will be doubled for the same length and pressure.

Q. 200—If a ring one inch in length and 12 inches in diameter were subjected to an internal pressure of 100 pounds to the square inch, what would be the force tending to pull it apart?

A.—$12\times100=1{,}200$ pounds.

Q. 201—Since there is a pull of 1,200 pounds in *both* directions why they would not the stress be *twice* 1,200 pounds.

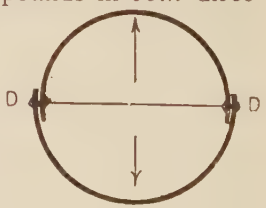


FIG. 39.

A.—Because the stresses are exerted against each other. If two men pull against each other on a rope, one cannot pull more than the other can hold or pull against him and though they are *both* pulling an equal amount, the stress in the rope can be only what each (not both) pulls. The effect would be the same as though the stronger man were replaced by an immovable post or wall to which the rope was attached. He simply serves,

as would the post or wall, for the weaker man to pull against to the extent of his strength. One side of the boiler or cylinder pulls against the other side in the same way, and the tension in the iron is the force with which each (not both) side pulls.

Q. 202.—By what is this effort of the pressure to tear the ring apart resisted?

A.—By the cohesion of the iron, or the force by which its molecules are held together.

Q. 203.—What is this cohesion of the iron called?

A.—Its tensile strength.

Q. 204.—How is the tensile strength of a metal ordinarily expressed?

A.—In pounds per square inch of section.

Q. 205.—What is the "tensile strength" of ordinary boiler iron?

A.—About 40,000 to 45,000 pounds per square inch.

Q. 206.—What do you mean when you say that the tensile strength is 40,000 pounds per square inch?

A.—That it would take a pull of 40,000 pounds applied in the direction of its length to break a bar of it one inch square, or one-half inch wide and two inches long, or one-quarter inch wide and 4 inches long, or of any other dimensions so long as the area exposed by the break in each of the pieces into which it is divided is one square inch.

Q. 207.—Suppose the ring in Fig. 39, twelve inches in diameter and one inch wide, to be one-quarter of an inch thick; what pressure would be required to break it if the tensile strength of the iron was 42,000 pounds?

A.—In order that the ring may be separated into halves it must be torn apart at two points, as *D* and *D*, and there will be exposed two areas 1-4 × 1 inch, or of one-quarter of a square inch each, or one-half a square inch in all. To tear these surfaces apart will require a force of 42,000 ÷ 2 = 21,000 pounds. This force or pressure is to be exerted upon 12 square inches, and the pressure per square inch will be 21,000 ÷ 12 = 1,750 pounds.

Q. 208.—Would this operation apply to any length of cylinder as well as to a ring one inch wide?

A.—Yes; for while each added inch of length gives more iron to be torn apart, it gives also a proportionately greater surface for the pressure to act upon. If the ring were two

inches wide instead of one inch there would be twice the area for the pressure to act upon, but also twice the section of metal to be torn apart. It will be easily seen by arranging the operation as follows that the lengths cancel each other:

$$\frac{\text{thickness} \times \text{length} \times \text{tensile strength} \times 2}{\text{diameter} \times \text{length}} = \text{bursting pressure per sq. in.}$$

Q. 209—How may the above operation or formula be simplified?

A.—By dividing both numerator and denominator by 2, and cancelling the lengths, which does not change the value of the expression, leaves out the 2 above the line, and changes the divisor or denominator to the radius, which is one-half the diameter, making the formula

$$\frac{\text{thickness} \times \text{tensile strength}}{\text{radius}} = \text{bursting stress.}$$

Q. 210—Explain why it is allowable to thus simplify the operation.

A.—Instead of considering the whole force (diameter $\times$ pressure) as resisted by the two sections *a* and *b*, we can consider one-half that force (radius $\times$ pressure) as resisted by one of the sections.

Q. 211—In accordance with this reasoning and formula, give a rule for finding the pressure at which a cylindrical vessel will burst.

A.—Multiply the thickness of the thinnest sheet in inches by the tensile strength in pounds per square inch, and divide by the radius in inches. The quotient will be the bursting pressure in pounds per square inch.

Q. 212—What is a "factor of safety?"

A.—A number by which the bursting stress is divided to get the allowable working stress. In order to insure safety, boilers and other engineering structures are run on pressures not exceeding one-third or one-fourth of the pressure at which they would figure to fail. If used at one-fifth, the factor of safety would be 5; at one-quarter, 4, etc.

Q. 213—What factor of safety is commonly used in steam boilers?

A.—Three and one-half to five.

Q. 214—Give the United States marine rule for the amount of pressure allowable on a steam boiler.

A.—"*Multiply one-sixth of the lowest tensile strength found stamped on any plate in the cylindrical shell by the thickness, expressed in inches or parts of an inch, of the thinnest plate in the same cylindrical shell, and divide by the radius or half diameter, also expressed in inches, and the sum will be the pressure allowable per square inch of surface for single riveting, to which add twenty per centum for double riveting.*"

Q. 215—Is not the factor of safety in this rule 6?

A.—No; for the stress allowed is one-sixth of the full tensile strength of the iron, and not of the actual riveted joints.

Q. 216—What percentage of the full strength of the iron is retained in a riveted joint?

A.—Upon the basis of some experiments made in 1838 by Sir William Fairbairn, the strength of single riveted seams is ordinarily taken at 56 per cent. of the sheet, and of double riveted seams at 70 per cent. Properly made seams, however, exceed these percentages.

Q. 217—With these values, what factor of safety does the marine rule allow for single riveting?

A.—$6 \times .56 = 3.36$.

Q. 218—For double riveting?

A.—The resistance to rupture, or the bursting pressure, of the double riveted joint is

$$\text{tensile strength} \times .70$$

The allowable stress with a double riveted joint is

$$\frac{\text{tensile strength} \times 1.20}{6} = \text{tensile strength} \times .2.$$

Dividing the bursting stress by the allowable stress we get as a factor of safety

$$\frac{\text{tensile strength} \times .70}{\text{tensile strength} \times .2} = 3.5$$

Q. 219—What does the double riveting and single riveting of the rule refer to?

A.—The longitudinal seams.

Q. 220—Why the longitudinal seams?

A.—Because the stress is greater in the longitudinal than in the roundabout seams.

Q. 221—Show how the stress per unit of section is greater on the longitudinal than on the roundabout seams.

A.—To pull the boiler apart in the direction of its length, as indicated by the arrows in Fig. 40, we have the pressure per square inch multiplied by the number of square inches in the

head. To resist this pull, we have the entire circumference of the sheet. The pressure and the thickness of the sheet being the same for both directions, they need not be taken into

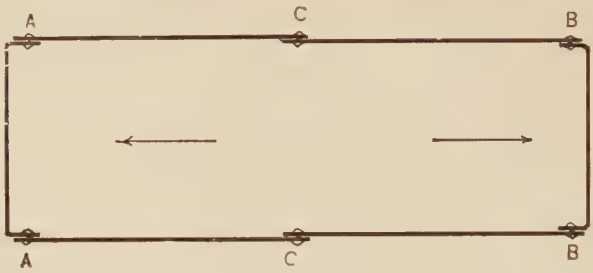


FIG. 40.

account. The area of the head is

$$\text{Diameter}^2 \times .7854.$$

and the circumference is

$$\text{Diameter} \times 3.1416$$

so that we have for each inch of the roundabout seam a pull proportional to

$$\frac{\text{Diameter}^2 \times .7854}{\text{Diameter} \times 3.1416} = \frac{\text{Diameter}}{4}$$

We have already seen that the stress on each inch in length of the boiler is proportional to

$$\frac{\text{Diameter}}{2}$$

so it is plain that whatever the diameter, the stress on the longitudinal seams per unit of section will be twice that upon the roundabout seams.

Q. 222 —Why is thicker iron used with larger diameters?

A.—Because the stress upon the longitudinal seam increases with the diameter, and more metal must be presented to meet it.

Q. 223 —What is "shearing strength?"

A.—The resistance which a material offers to being sheared or cut across, as the rivet in Fig. 41.

Q. 224 —When is a rivet said to be in "single shear?"

A.—When the tendency is to cut it across in a single plane, as in Fig. 41.

Q. 225 —When is a rivet said to be in "double shear?"

A.—When the tendency is to cut it across in two planes, as in Fig. 42.

Q. 226—Which is the stronger?

A.—The double shear, for with it twice as much surface must be separated as with the single, and it requires nearly twice the force to shear a bolt or rivet in double as in single shear.

Q. 227—How does the shearing strength of wrought iron compare with its tensile strength?

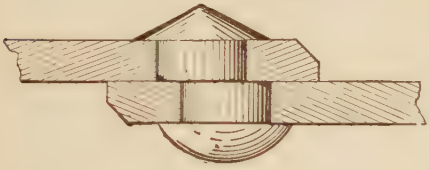


FIG. 41.

A. — The shearing strength is about 80 per cent. of the tensile strength.

Q. 228—How may a riveted joint give way?

A.—Either by tearing the plate between the rivets, as in Fig. 43, or by shearing off the rivets, as in Figs. 41 and 42.

Q. 229—What kind of a riveted joint will have the greatest strength?

A.—That in which the tensile strength of the sheet between the rivet holes is just equal to the shearing strength of the rivets.

Q. 230—Why?

A.—Because the joint can be no stronger than its weakest part. If you give the rivets more pitch in order to increase the sheet section, you lessen the number of rivets, increase the stress on each, and the joint will fail by shearing. If, on the other hand, you put in more rivets, you reduce the section of plate between them, and the plate will pull apart. You can only gain strength in one factor by sacrificing strength in the other, and the greatest strength will obviously be when both are equal.

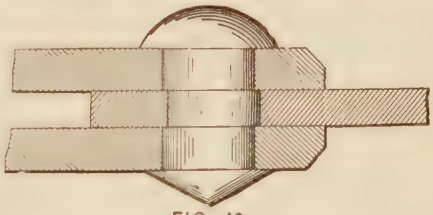


FIG. 42

Q. 231—How can you add to the rivet section without decreasing the plate section?

A.—By placing the rivets, instead of in a single row, as in Fig. 44, in two rows, as in Fig. 45, or in three rows, as in Fig. 46, the distance between the rows being such as to maintain the required distance between any two rivets. In this way the

number of rivets subjected to shearing stress can be greatly increased without reducing the sheet section subjected to tensile stress.

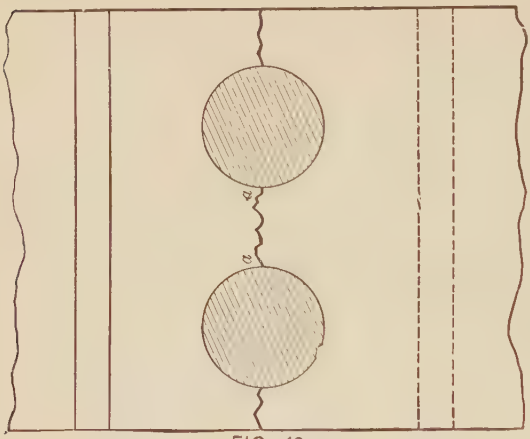


FIG. 43.

Q. 232 — Why are the rivets spaced farther apart in double than in single riveting?

A.—To give a cross sectional area of plate equivalent in strength to the increased area of the rivets, remembering that in the strongest joint these must be equal.

Q. 233 —Is triple riveting stronger than double?

A.—It is, for the same reason that double is stronger than single.

Q. 234 — Why is the practice of multiplying the rows of rivets not carried farther?

A.—Because the "pitch" or distance between centers in the triple riveted joint becomes as great as is consistent with a tight joint. Suppose that in a triple riveted joint the tensile strength of the sheet between the rivets was just equal to the shearing strength of the rivets. It would add nothing to the strength of the joint to add another row of rivets at the same

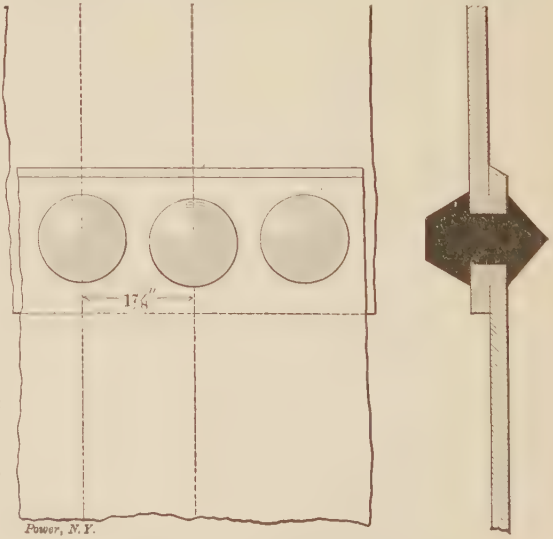


FIG. 44—SINGLE RIVETED JOINT.

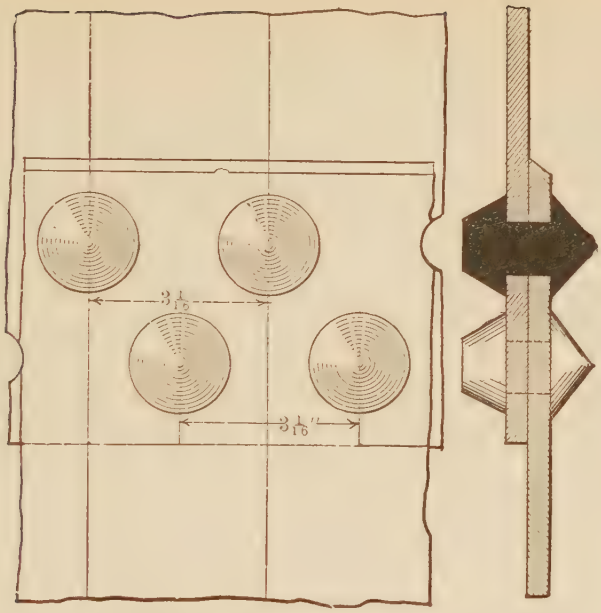


FIG. 45—DOUBLE RIVETED JOINT.

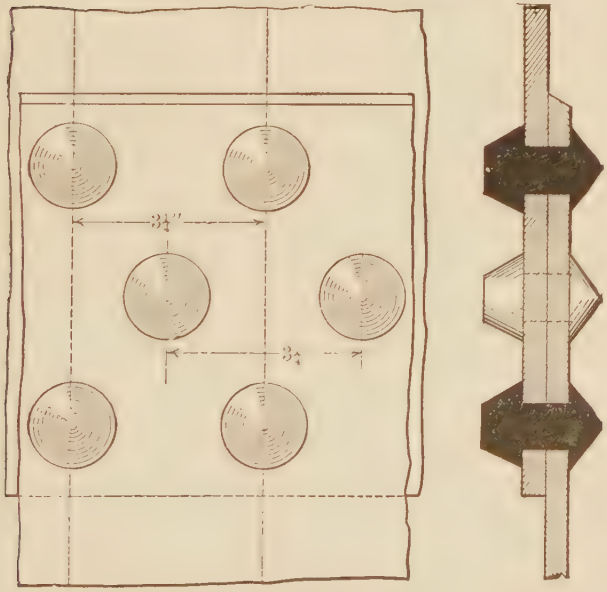


FIG. 46—TRIPLE RIVETED JOINT.

pitch, for the joint has rivet strength enough now, and would fail at the same stress in the sheet, even if a fourth row of rivets were added. Its strength can only be increased by increasing the pitch, or distance apart, of the rivets, and they are already as far apart in a triple riveted joint as they can be and keep the joint from leaking.

Q. 235—Assuming the tensile strength of the plate and the shearing strength of the rivets to be equal per unit of section, how would you determine the proper pitch for a single riveted seam?

A.—On this assumption of equal shearing and tensile strengths the area *abcd* of the sheets between the rivets, Fig. 47,

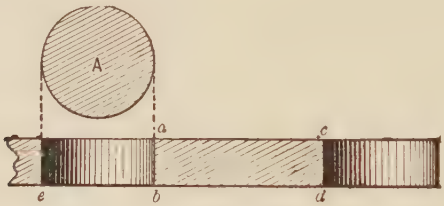


FIG. 47.

must be equal to the area of the rivet *A*. The area of sheet equals its thickness *a b* multiplied by its length *a c*,
and

$$\text{area of rivet} = \text{thickness} \times \text{length of plate},$$

and

$$\text{length} = \frac{\text{area of rivet}}{\text{thickness of plate.}}$$

In other words, dividing the area of the rivet by thickness of the plate gives the necessary length of sheet between rivets, and adding the diameter of the rivet gives the pitch or distance between rivet centers.

Q. 236—How would you find the proper pitch when the shearing strength of the rivets was known to be 38,000 pounds and the tensile strength of the plate 55,000 pounds per square inch?

A.—Here the area of the rivet multiplied by 38,000 must equal the area of the plate multiplied by 55,000, or

$$\text{Area of rivet} \times 38{,}000 = \text{thickness} \times \text{length} \times 55{,}000.$$

$$\text{Length} = \frac{\text{Area of rivet} \times 38{,}000}{\text{thickness plate} \times 55{,}000}$$

to which add the diameter of the rivet to get the pitch.

Rule:—Divide the cross-sectional area of the rivet hole multiplied by the shearing strength of the rivet, by the thickness of the plate multiplied by its tensile strength, and to the quotient add the diameter of the rivet. The sum will be the required pitch or distance between rivet centers.

Q. 237 —How do you determine the pitch for equal tensile and shearing strengths of joint when two or more rows of rivets are used?

A.—If more than one row of rivets is used, it is obvious that the area *abcd*, Fig. 47, must be increased accordingly to equal the area of the increased number of rivets. In the case of double riveted seams the cross-sectional area of rivet presented to shearing is doubled and the area of plate between the rivets must be doubled also. This can be done in the above rule by multiplying the cross-sectional area of the rivet hole by the number of rows of rivets, as two for double, three for triple, etc., before dividing by the thickness. The limit of pitch for tightness with this joint, however, is reached at double riveting except with thick plates and double butt-strap-joints.

Q. 238 —What is a butt-joint?

A.—A joint in which the edges of the boiler sheet are butted together, as Fig. 48, instead of being lapped, welts or butt-straps being used, usually upon both sides of the plate, as shown.

Q. 239 —About what is its percentage of efficiency?

A.—About 87.5.

Q. 240 —To what is this increase of efficiency due?

A.—To the fact that the rivets in the middle of the joint are in double-shear and the plate section is increased by the wide spacing of the last row of rivets, while a tight joint is assured by the close spacing of the rivets along the calking edge of the outside butt-strap.

Q. 241 —What is the weakest point in this joint, assuming the tensile strength of the plate to be 55,000 pounds, thickness 3-8 = .375 inch; shearing strength of the rivets to be 38,000 pounds per square inch of section in single shear, 70,300 pounds in double-shear; rivets 13-16 = 0.8125 inches diameter; pitch 3 1-4 in inside rows, and 6 1-2 outside?

A.—Along the line *AB*.

Q. 242 —How do you determine it?

A.—The resistance of the plate to failure from tensile stress will be $.375 \times (6.5 - 0.8125) \times 55{,}000 = 117{,}305$ pounds.

In order to separate by shearing there would have to be cut in two one rivet in single-shear and four in double-shear. The cross sectional area of a 13-16 rivet is .5185 of a square inch, and one rivet in single-shear will hold .5185 × 38,000 = 19,703 pounds, and four rivets in double-shear will hold 4 ×

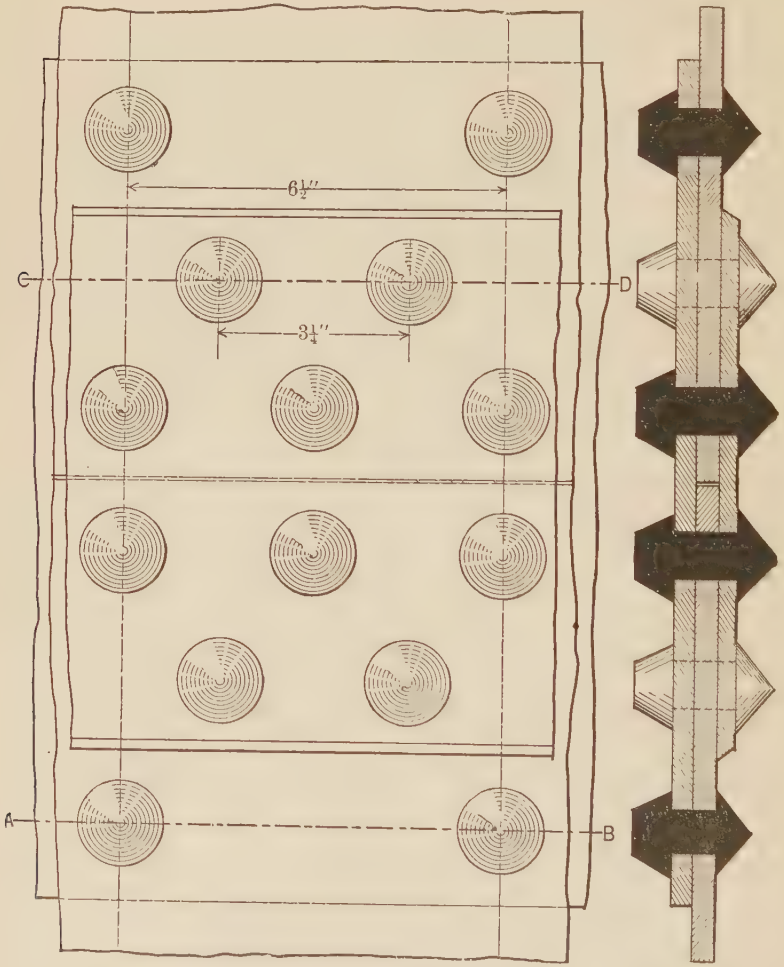


FIG. 48—DOUBLE WELT BUTT JOINT.

.5185 × 70,300 = 145,802 pounds, and the total strength of the rivets is 19,703 + 145,802 = 165,505 pounds, which is largely in excess of the tensile strength of the plate, so that the fracture would occur in the plate.

Q. 243—Why may not the fracture occur in the plate where it is reduced by the narrower spacing, as along the line *C D?*

A.—If the fracture does not occur back of the first rivets you will have two plates to pull apart, and the plate resistance will be increased to an extent which will more than compensate for the reduction of area caused by the narrower spacing.

Q. 244—What is the requirement of the United States marine rules in regard to butt-straps?

A.—*"Where butt-straps are used in the construction of marine boilers the straps for single butt-strapping shall in no case be less than the thickness of the shell plates; and where double butt-straps are used the thickness of each shall in no case be less than five-eighths of the thickness of the shell plates."*

Q. 245—How is the tendency to distortion in flat surfaces under pressure resisted in boiler making?

A.—By bracing or staying.

Q. 246—What stress is allowed on the diagonal braces of horizontal tubular boilers?

A.—The Supervising Inspectors place the limit at 6,000 pounds per square inch of sectional area.

Q. 247—With this allowance how would you determine the maximum stress to be put upon a brace of given diameter?

A.—Multiply 6,000 by the square of the diameter and by .7854.

Q. 248—How do you determine the stress which each stay sustains?

A.—By multiplying the pressure per square inch by the area in square inches bounded by lines drawn midway between the given stay and its neighbors (see Fig. 49) where the area of the rectangle *ABCD*, drawn between bolt centers, is equal to the area bounded by the lines drawn midway between the bolt *A* and its neighbors. When the stays are set in squares this area will be the square of the distances between centers, stays 8 inches apart in both directions each supporting the pressure on $8 \times 8 = 64$ square inches.

Q. 249—How do you determine the stress on each stay bolt in a structure like Fig. 49?

A.—The area which each bolt supports is that inclosed between lines drawn centrally between the rows of rivets, as the shaded portion around rivet *A*. This area is equivalent to the product of the vertical distance *AD* and horizontal distance *AB* between the rows, and, since these are equal, is in this

case a square. This area multiplied by the pressure per square inch gives the stress on each bolt.

Q. 250—Do you not consider the area of both plates, since the bolt supports them both?

A.—No. See answer 201.

Q. 251—What portion of a horizontal tubular boiler requires bracing?

A.—That portion of the head above the tubes. It is usual to assume that spaces two inches wide above the tubes and for two inches around the edge are supported by the tubes and flange, so that the area to be braced consists of that inclosed in the dotted line in Fig. 50.

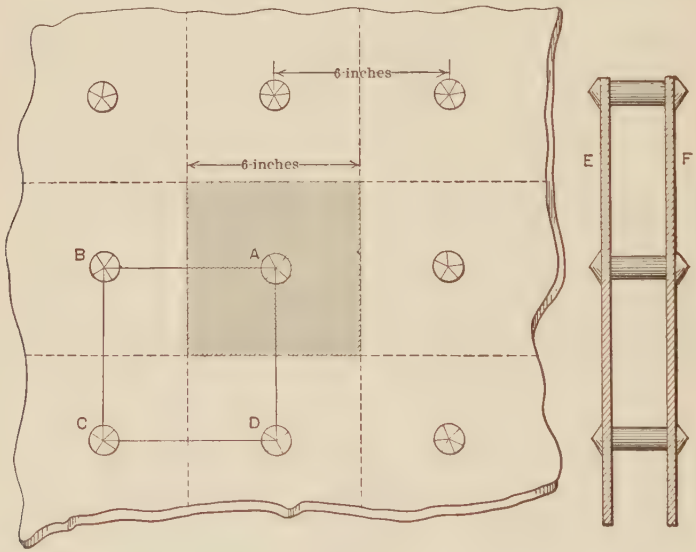


FIG. 49.

Q. 252—What is such an area called?

A.—A "segment" of a circle.

Q. 253—What is a sector of a circle?

A.—A sector is that part of a circle bounded by an arc and its two radii, as *BECD,* Fig. 51. It includes the segment as *BEHD.*

Q. 254—How do you find the area of a sector?

A.—By multiplying one-half the length of the arc by the radius.

Q. 255—How do you find the area of a segment?

A.—By finding first the area of the containing sector, and subtracting the area of the triangle, as *DEC* below the segment.

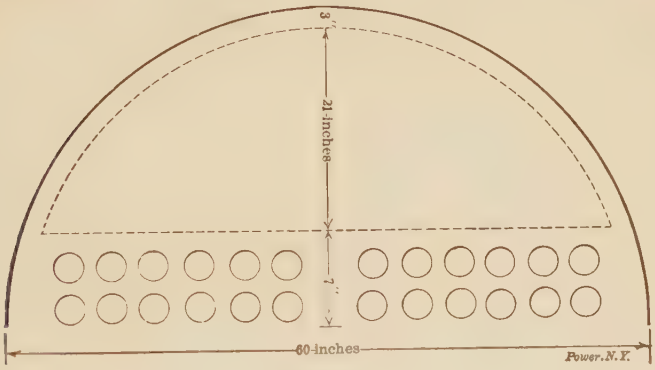


FIG 50.

Q. 256—How do you find the area of a triangle?

A.—By multiplying one-half the base by the altitude. In Fig. 51 it will be readily seen that if the portion of the triangle on one side of the diameter were placed with its diagonal beside the diagonal of the other half it would form a rectangle, the length of which would be that of the line *DH* (half the base), and the altitude *HC;* and the area, of course, would be the product of these two lengths.

Q. 257—Is there any way of finding the area of a segment without having to measure the arc?

A.—Yes, by means of a table of circular segments, such as Table III.

Q. 258—How is this used?

A.—Divide the height of the segment *HB,* Fig. 51, by the diameter of the circle of which it is a part. Find the number in the column headed "height" most nearly corresponding with the quotient, and multiply the corresponding area by the square of the diameter.

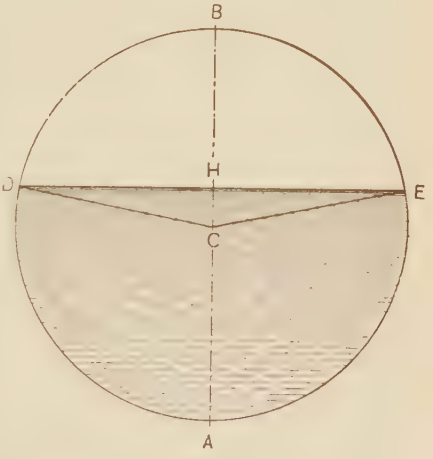


FIG. 51.

TABLE III.

AREA OF CIRCULAR SEGMENTS.

Height	Area.	Height	Area	Height	Area	Height	Area
.000	.00000	.060	.01924	.120	.05338	.180	.09613
.001	.00004	.061	.01972	.121	.05404	.181	.09690
.002	.00012	.062	.02020	.122	.05469	.182	.09767
.003	.00022	.063	.02068	.123	.05535	.183	.09845
.004	.00034	.064	.02117	.124	.05600	.184	.09922
.005	.00047	.065	.02166	.125	.05666	.185	.09200
.006	.00062	.066	.02215	.126	.05733	.186	.10077
.007	.00078	.067	.02265	.127	.05799	.187	.10153
.008	.00095	.068	.02315	.128	.05866	.188	.10233
.009	.00114	.069	.02366	.129	.05933	.189	.10317
.010	.00133	.070	.02417	.130	.06000	.190	.10390
.011	.00153	.071	.02468	.131	.06067	.191	.10469
.012	.00175	.072	.02520	.132	.06135	.192	.10547
.013	.00197	.073	.02571	.133	.06203	.193	.10626
.014	.00220	.074	.02624	.134	.06271	.194	.10705
.015	.00244	.075	.02676	.135	.06339	.195	.10784
.016	.00268	.076	.02729	.136	.06407	.196	.10864
.017	.00294	.077	.02782	.137	.06476	.197	.10943
.018	.00320	.078	.02836	.138	.06545	.198	.11023
.019	.00347	.079	.02889	.139	.06614	.199	.11102
.020	.00375	.080	.02943	.140	.06683	.200	.11182
.021	.00403	.081	.02997	.141	.06753	.201	.11262
.022	.00432	.082	.03053	.142	.06822	.202	.11343
.023	.00461	.083	.03108	.143	.06892	.203	.11423
.024	.00492	.084	.03163	.144	.06963	.204	.11504
.025	.00523	.085	.03219	.145	.07033	.205	.11584
.026	.00555	.086	.03275	.146	.07103	.206	.11665
.027	.00587	.087	.03331	.147	.07174	.207	.11746
.028	.00619	.088	.03385	.148	.07245	.208	.11827
.029	.00653	.089	.03444	.149	.07316	.209	.11908
.030	.00687	.090	.03501	.150	.07387	.210	.11990
.031	.00721	.091	.03538	.151	.07459	.211	.12071
.032	.00756	.092	.03616	.152	.07530	.212	.12153
.033	.00792	.093	.03674	.153	.07603	.213	.12235
.034	.00828	.094	.03732	.154	.07675	.214	.12317
.035	.00864	.095	.03790	.155	.07747	.215	.12399
.036	.00901	.096	.03850	.156	.07819	.216	.12481
.037	.00939	.097	.03909	.157	.07892	.217	.12563
.038	.00977	.098	.03968	.158	.07965	.218	.12646
.039	.01015	.099	.04028	.159	.08038	.219	.12729
.040	.01054	.100	.04087	.160	.08111	.220	.12811
.041	.01093	.101	.04148	.161	.08185	.221	.12894
.042	.01133	.102	.04208	.162	.08258	.222	.12977
.043	.01173	.103	.04269	.163	.08332	.223	.13060
.044	.01214	.104	.04330	.164	.08406	.224	.13144
.045	.01255	.105	.04391	.165	.08480	.225	.13227
.046	.01297	.106	.04452	.166	.08554	.226	.13311
.047	.01340	.107	.04514	.167	.08629	.227	.13395
.048	.01382	.108	.04576	.168	.08704	.228	.13478
.049	.01425	.109	.04638	.169	.08778	.229	.13562
.050	.01468	.110	.04701	.170	.08854	.230	.13646
.051	.01512	.111	.04763	.171	.08929	.231	.13731
.052	.01556	.112	.04826	.172	.09004	.232	.13815
.053	.01601	.113	.04889	.173	.09080	.233	.13899
.054	.01646	.114	.04953	.174	.09155	.234	.13984
.055	.01691	.115	.05016	.175	.09231	.235	.14069
.056	.01737	.116	.05080	.176	.09307	.236	.14154
.057	.01783	.117	.05145	.177	.09383	.237	.14239
.058	.01830	.118	.05209	.178	.09460	.238	.14324
.059	.01877	.119	.05274	.179	.09537	.239	.14409

TABLE III (Concluded).

AREA OF CIRCULAR SEGMENTS.

Height	Area	Height	Area	Height	Area	Height	Area
.240	.14494	.300	.19817	.360	.25455	.420	.31304
.241	.14580	.301	.19908	.361	.25551	.421	.31403
.242	.14665	.302	.20000	.362	.25647	.422	.31502
.243	.14752	.303	.20092	.363	.25743	.423	.31600
.244	.14837	.304	.20184	.364	.25839	.424	.31699
.245	.14923	.305	.20276	.365	.25936	.425	.31798
.246	.15009	.306	.20368	.366	.26032	.426	.31897
.247	.15096	.307	.20460	.367	.26128	.427	.31996
.248	.15182	.308	.20553	.368	.26225	.428	.32095
.249	.15268	.309	.20645	.369	.26321	.429	.32194
.250	.15355	.310	.20738	.370	.26418	.430	.32293
.251	.15442	.311	.20830	.371	.26514	.431	.32392
.252	.15528	.312	.20923	.372	.26611	.432	.32491
.253	.15615	.313	.21015	.373	.26708	.433	.32590
.254	.15702	.314	.21108	.374	.26805	.434	.32689
.255	.15789	.315	.21201	.375	.26901	.435	.32788
.256	.15876	.316	.21294	.376	.26998	.436	.32887
.257	.15964	.317	.21387	.377	.27095	.437	.32987
.258	.16051	.318	.21480	.378	.27192	.438	.33086
.259	.16139	.319	.21573	.379	.27289	.439	.33185
.260	.16226	.320	.21667	.380	.27386	.440	.33284
.261	.16314	.321	.21760	.381	.27483	.441	.33384
.262	.16402	.322	.21853	.382	.27580	.442	.33483
.263	.16490	.323	.21947	.383	.27678	.443	.33582
.264	.16578	.324	.22040	.384	.27775	.444	.33682
.265	.16666	.325	.22134	.385	.27872	.445	.33781
.266	.16755	.326	.22228	.386	.27969	.446	.33880
.267	.16843	.327	.22322	.387	.28070	.447	.33980
.268	.16932	.328	.22415	.388	.28164	.448	.34079
.269	.17020	.329	.22509	.389	.28262	.449	.34179
.270	.17109	.330	.22603	.390	.28359	.450	.34278
.271	.17198	.331	.22697	.391	.28457	.451	.34378
.272	.17287	.332	.22792	.392	.28554	.453	.34577
.273	.17376	.333	.22886	.393	.28652	.455	.34776
.274	.17465	.334	.22980	.394	.28750	.457	.34975
.275	.17554	.335	.23074	.395	.28848	.459	.35174
.276	.17644	.336	.23169	.396	.28945	.462	.35174
.277	.17733	.337	.23263	.397	.29043	.464	.35673
.278	.17823	.338	.23358	.398	.29141	.466	.35873
.279	.17912	.339	.23453	.399	.29239	.468	.36072
.280	.18002	.340	.23547	.400	.29337	.470	.36272
.281	.18092	.341	.23642	.401	.29435	.471	.36371
.282	.18182	.342	.23737	.402	.29533	.473	.36571
.283	.18272	.343	.23832	.403	.29631	.475	.36771
.284	.18362	.344	.23927	.404	.29729	.477	.36971
.285	.18452	.345	.24025	.405	.29827	.479	.37170
.286	.18542	.346	.24117	.406	.29926	.482	.37470
.287	.18633	.347	.24212	.407	.30024	.484	.37670
.288	.18723	.348	.24307	.408	.30122	.486	.37870
.289	.18814	.349	.24403	.409	.30220	.488	.38070
.290	.18905	.350	.24498	.410	.30319	.490	.38270
.291	.18996	.351	.24593	.411	.30417	.491	.38370
.292	.19086	.352	.24689	.412	.30516	.492	.38470
.293	.19177	.353	.24784	.413	.30614	.493	.38570
.294	.19268	.354	.24880	.414	.30712	.494	.38670
.295	.19360	.355	.24976	.415	.30811	.495	.38770
.296	.19451	.356	.25071	.416	.30910	.496	.38870
.297	.19543	.357	.25167	.417	.31008	.497	.38970
.298	.19634	.358	.25263	.418	.31107	.498	.39070
.299	.19725	.359	.25359	.419	.31205	.499	.39170
						.500	.39270

Q. 259—What would be the area of the segment inclosed by the dotted line in Fig. 50 if the boiler were 60 inches in diameter and the top of the first row of tubes five inches above the boiler center?

A.—The height would be $30 - (5 + 3 + 2) = 20$ inches. The diameter is $60 - (2 \times 3) = 54$ inches. The quotient of the height divided by the diameter is $20 \div 54 = 0.37$. The value corresponding with this for a diameter of unity would be, by the table 0.26418, and as the areas of circles measure as the squares of their diameters the area of a 54-inch circle would be

$$54 \times 54 \times 0.26418 = 770.349 \text{ square inches.}$$

Q. 260—How many one-inch braces at each end would it take to brace a five-foot boiler for 100 pounds pressure, assuming each brace to be good for 6,000 pounds, and the top row of tubes to be five inches above the center.

A.—The area to be braced would be 843.61 square inches (see Ans. to Q. 259). The pressure upon the surface would be $843.61 \times 100 = 84{,}361$ pounds. If one brace sustains 6,000 pounds, it will take $84{,}361 \div 6{,}000 =$ about 14 braces.

Q. 261—How should these be disposed?

A.—They should be so disposed about the head as to equalize the stress on each, bringing them a little nearer together toward the center of the head to counteract the greater tendency to bulge.

Q. 262—How should they be connected to the shell?

A.—They should be widely distributed, some extending back to the second sheet.

Q. 263—What are the requirements of the United States marine rules with regard to braces and stays?

A.—"No braces or stays hereafter employed in the construction of steam boilers shall be allowed a greater strain than 6,000 pounds per square inch of section, and no solid or hollow screw bolt shall be allowed to be used in the construction of marine boilers in which salt water is used to generate steam unless said screw-bolt is protected by a socket. But such screw-bolts without sockets may be used in staying the fire boxes and furnaces of such boilers and elsewhere, when fresh water is used for generating steam in said boilers. Water used from a surface condenser shall be deemed fresh water. The flat surface at back-connection or back end of boilers may be stayed by the use of a tube, the ends of which being expanded in holes in each sheet, beaded and further secured by a bolt passing through the tube and secured by a nut. An allowance of steam shall be given from the outside diameter

of the pipe. For instance, if the pipe used be 1 1-2 inches in diameter outside with a 1 1-4 inch bolt through it, the allowance will be the same as if a 1 1-2 inch bolt were used in lieu of the pipe and bolt. And no brace or stay-bolt used in a marine boiler will be allowed to be placed more than 10 1-2 inches from center to center on fire-boxes, furnaces, and back-connections nor on these at greater distance than will be determined by the following formulas."

The working pressure allowed on flat surfaces with screw stay bolts and nuts, or plain bolt with single nut and socket, or riveted head and socket, will be determined by the following rule:—

"When plates 7-16 inch thick and under are used in the construction of marine boilers, using 112 as a constant, multiply this by the square of the thickness of the plate in sixteenths of an inch. Divide this product by the square of the pitch or distance from center to center of the stay-holes."

Examples—Plate 7-16 inch thick with socket-bolts or stays, 6-inch center, would be 112, the constant, multiplied by the square of 7, the thickness of the plates in sixteenths, which is 49; which would give 5,488, which, divided by the square of 6, which is 36, being the distance from center to center of the stays or the pitch, would be 152, the working pressure allowed, provided the strain on stay or bolt does not exceed 6,000 pounds per square inch of section.

Plates 1-4 inch thick, stay bolts spaced 4-inch center = $\frac{112 \times 16}{16}$ = 112 working pressure.

Plates 5-16 inch thick stay-bolts spaced 5-inch center = $\frac{112 \times 25}{25}$ = 112 working pressure.

Plates 5-16 inch thick stay-bolts spaced 6-inch center = $\frac{112 \times 25}{36}$ = 77 working pressure.

Plates 3-8 inch thick, stay-bolts spaced 6-inch center = $\frac{112 \times 36}{36}$ = 112 working pressure.

Plates above 7-16 inch thick, the pressure will be determined by the same rule, excepting the constant will be 120, then a plate 1-2 inch thick, stays spaced 7 inches from center to center

would be as follows: 120, the constant, multiplied by 64, the square of thickness in sixteenths of an inch, equals 7,680, which divided by the square of 7 inches (distance from center to center of stays), which is 49, would give 156 pounds working pressure.

Plates 3-4 or 12-16 of an inch thick, spaced 10 1-2 inches would be

$$\frac{120 \times 144}{110.25} = 156 \text{ working pressure.}$$

On other flat surfaces there may be used stay-bolts with ends threaded, having nuts on same, both on the outside and inside of plates. The working pressure allowed would be as follows: A constant 140 multiplied by the square of the thickness of plate in sixteenths of an inch, this product divided by the pitch or distance of bolts from center to center, squared, gives working pressure.

EXAMPLE:—A plate 3-4 inch thick, supported by bolts 14 inches apart would be

$$\frac{140 \times 144}{196} = 102 \text{ pounds working pressure.}$$

Same thickness of plate, with bolts 12-inch centers, would be.

$$\frac{140 \times 144}{144} = 140 \text{ pounds working pressure.}$$

Plates with bolts with double nuts and a washer at least one-half the thickness of the plate, and a size equal to two-fifths the pitch of stay-bolts, would be allowed with a constant 200, when riveted to plates, by rule as above.

EXAMPLE:—A plate 3-4 inch thick, with a washer 3-8 inch thick and 5.6 inches square, supported by bolts 14-inch center, would be $\frac{200 \times 144}{196} = 147$ pounds working pressure.

Spaced 15-inch centers, with a washer 3-8 inch thick and 6 inches square, supported by bolts 15-inch centers, would be

$$\frac{200 \times 144}{225} = 128 \text{ pounds working pressure.}$$

Plates fitted with double angle iron and riveted to plate with leaf at least two-thirds thickness of plate and depth at

least one-fourth of the pitch, would be allowed the same pressure as determined by formula for plate with washer riveted on.

EXAMPLE:—Plate 3-4 inch thick supported by angle-iron and supported by bolts, 14-inch centers, would be

$$\frac{200 \times 144}{196} = 146 \text{ pounds working pressure;}$$

but no flat surface shall be unsupported at a greater distance in any case than 16 inches, and such flat surfaces shall not be of less strength than the shell of the boiler and able to resist the same stress and pressure to the square inch. In allowing the stress on a screw staybolt, the diameter of the same shall be determined by the diameter at the bottom of the thread.

SECTION V.

Physical Properties of Steam.

Q. 264.—Of what is matter composed?
A.—Of a vast number of infinitely small molecules.

Q. 265.—Do these molecules touch each other?
A.—No; they are separated from each other by distances which are very considerable as compared with the diameter of the molecules themselves.

Q. 266.—What holds the molecules so that they do not separate completely?
A.—They are held together by the same force of universal gravitation which holds the earth and other planets to the sun, and the moon and other bodies of the earth.

Q. 267.—Are the molecules composing matter at rest?
A.—No; they are continually in motion.

Q. 268.—What is the nature of this motion?
A.—It is a complex motion. The molecules may rotate about their centers of gravity or about each other, or they may simply vibrate to and fro.

Q. 269.—What is heat?
A.—Heat is this motion of the molecules which has just been explained.

Q. 270.—What is the effect of the application of heat to matter?
A.—It increases the frequency and extent or amplitude of the vibrations and this by increasing the average distances between molecules causes the matter to increase in size or expand.

Q. 271.—How is temperature measured?
A.—By the expansive effect of heat upon matter; usually upon a body of mercury enclosed in a vacuum tube, as in an ordinary thermometer.

Q. 272.—What is the unit of temperature?

A.—The thermometric degree. Of these there are two, the Centigrade and Fahrenheit.

Q. 273.—Describe the Centigrade scale.

A.—The zero of the Centigrade thermometer is at the freezing point of water, and the 100 degree division is at the boiling point of water.

Q. 274.—Describe the Fahrenheit scale.

A.—In the Fahrenheit scale the distance between the freezing and boiling point is divided into 180 degrees. The zero of the scale corresponds with the temperature of a mixture of salt and ice. This was the coldest mixture known at the time that the scale was constructed and was supposed to represent absolute cold and so marked zero. It was found that the distance between the zero and the freezing point marks was equal to 32 of the 180 divisions; consequently the freezing point was marked 32 and the boiling point $32 + 180 = 212$.

Q. 275.—Explain the conversion of Centigrade temperature into Fahrenheit temperature.

A.—The 100 degrees of the Centigrade scale lying between the freezing and boiling points equal 180 on the Fahrenheit scale, so that 1 degree Centigrade equals 9-5 of a degree Fahrenheit; consequently the temperature expressed in degrees Centigrade must be multiplied by 9-5 to convert it into degrees Fahrenheit. This will give the degree F. above freezing point and consequently 32 degrees must be added to get the temperature of the Fahrenheit scale.

Q. 276.—The temperature of water on the Centigrade scale is 20 degrees. What is it on the Fahrenheit?

A.—$20 \times 9\text{-}5 = 180\text{-}5 = 36$. $36 + 32 = 68$ temperature in degrees Fahrenheit.

Q. 277.—Explain the conversion of degrees Fahrenheit into degrees Centigrade.

A.—First subtract 32 from the temperature in Fahrenheit degrees, in order to get the reading above the freezing point; then multiply by 5-9 as the division on the Fahrenheit scale are 5-9 as long as the divisions on the Centigrade scale. The result is the temperature in Centigrade degrees.

Q. 278.—If a body has a temperature of 5 degrees below zero on the Fahrenheit thermometer, what would be the reading on the Centigrade scale?

A.—The temperature F. is 5° below zero, or — 5°. Then

— 5 — 32 = — 37. And — 37 × 5-9 = — 185-9 = — 20 5-9 degrees, or the temperature is 20 5-9 degrees below 0 on the Centigrade scale.

Q. 279. —What is the quantity of heat?

A.—There must be a distinction made between temperature, or intensity of heat and quantity of heat. If a cup of water be taken from a pailful both will be of the same temperature or intensity, but it is very evident that the quantity of heat in put into the matter is measured by the amount of matter as well as the degrees of temperature through which it is raised.

Q. 280. —What is the unit of quantity of heat?

A.—The British Thermal Unit, usually abbreviated to B. T. U.

Q. 281. —What is the B. T. U.

A.—The amount of heat required to raise one pound of water through one degree Fahrenheit.*

Q. 282. —Suppose a pail to contain 50 pounds of water at 60° F. Heat is applied until the temperature is 90°. How many B. T. U. have been imparted to the water?

A.—The rise in temperature has been 90 — 60 = 30 degrees. One heat unit is one pound raised one degree, so that to raise 50 pounds 30 degrees requires 50 × 30 = 1,500 B. T. U.

Q. 283. —What is a solid?

A.—A solid is a body in which the motion of the molecules is about fixed points. Each molecule retains its position in the body with respect to the other molecules, and the attractive force which holds the molecules together is in excess of the centrifugal force due to their motion, so that it is difficult to pull the body apart or alter its shape.

Q. 284 —What is a liquid?

A.—A liquid is a substance in which the centrifugal force of the molecules is so nearly equal to the mutual attraction or cohesion that the positions of the molecules with reference to each other is easily changed. You cannot push your finger into a brick because the molecules adhere too tenaciously to be easily pushed aside; but in a liquid this attraction has become so weak that the molecules yield easily to the

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*Strictly, the amount of heat required to raise a pound of water through one degree F. at its maximum density, between 30° and 40° F. The specific heat increases with the temperature so that it takes a little more heat for instance to raise a pound of water from 200° to 201° for instance than from 50° to 51°. This may be seen by comparing the "Temperature" and "Heat in the Water" columns in Table IV. The difference is so slight, however, that only .9 of a unit is gained in the whole range from freezing to boiling, and for anything but scientifically accurate work the heat unit to a degree is sufficiently accurate.

thrust of the finger, and the mass conforms to the shape of the containing vessel.

Q. 285 —What is gas?

A.—A substance in which the centrifugal force due to the motion of the molecules is so great as to overcome entirely the mutual attraction. The molecules then fly straight forward according to the ordinary laws of motion until they either strike other molecules or the sides of a containing vessel; in which case they rebound, with substantially their original velocity. If the molecules were in space they would fly off to infinity, but if confined in a vessel they continually strike against the sides, thus causing the pressure which a gas exerts in a closed vessel.

Q. 286 —What is steam?

A.—Steam is the vaporous or gaseous form of the substance known as water in the liquid state and as ice in the solid.

Q. 287 —At what temperature can this substance exist as a solid?

A.—At any temperature up to 32 degrees F.

Q. 288 —If a piece of ice is placed in a vessel containing water and heat is applied, what will happen?

A.—The temperature of the ice will gradually rise until it reaches 32 degrees, when the ice will commence to melt, but the temperature of the water will not rise above 32 degrees until all the ice is melted.

Q. 289 —Then what becomes of the heat supplied to the water?

A.—It has been expended in melting the ice, that is, it has caused the motion of the molecules in the solid to become so great as to reach the condition described in the answer to Q. 284.

Q. 290 —What is the heat thus expended known as?

A.—It is known as the latent heat of fusion or liquefaction.

Q. 291 —After the ice melts what happens?

A.—The temperature of the water will gradually rise until finally the liquid commences to boil. If the liquid is in a vessel open to the atmosphere at the sea level, its temperature at this time will be 212° F.

Q. 292 —Upon what does the temperature at which water will boil depend?

A.—Upon the pressure acting on its surface.

Q. 293 —How does this affect the boiling point?

A.—The greater the pressure, the higher will be the temperature of the water before it boils.

Q. 294—Why is this?

A.—Because the molecules are held in place by the combined effect of the external pressure, and their own mutual attraction, and the motion of the molecules which is produced by the heat must be great enough to overcome this combined force; therefore if the external pressure is increased more heat must be applied before the water will boil, and consequently the temperature will be raised.

Q. 295—Can water be boiled at 32 degrees?

A.—Yes, if the pressure is reduced to .089 pounds per square inch. See third column of Table IV.

Q. 296—At what temperature will water boil at an absolute pressure of 5 pounds?

A.—This corresponds to a vacuum of 10 pounds or 19.74 inches and the boiling point at that pressure is 162.3°, as shown in the third column of Table IV.

Q. 297—What is the boiling point at 60 pounds absolute pressure?

A.—292.5° as shown in the third column of Table IV.

Q. 298—What will be the boiling point at 130 pounds absolute?

A.—347.1 as shown in the third column of Table IV.

Q. 299—What is the act of boiling?

A.—It is the separation of the molecules from each other to such an extent as to totally destroy their mutual attraction, as described in Q. 285. The water is then changed into a vapor, and this gas is steam, as stated in Q. 286.

Q. 300—Will the temperature continue to rise after the water starts boiling?

A.—No, it remains stationary.

Q. 301—What becomes of the heat put into the water after the boiling point is reached?

A.—It is consumed in increasing the average distance between the molecules, tearing them entirely apart, and changing the water into steam.

Q. 302—What name is given to the heat thus expended?

A.—It is called the latent heat of evaporation.

Q. 303—What is sensible heat?

A.—It is heat that shows on the thermometer.

Q. 304—How does the latent heat of steam compare with sensible heat?

A.—At atmospheric pressure the latent heat is about five times as great. The sensible heat is 180.9, as shown in the fourth column of Table IV while the latent heat is 965.7 as shown in the sixth column of the table.

Q. 305—What is the total heat?

A.—It is the entire amount of heat required to change a pound of water at 32° F. into steam at the given pressure and is therefore the sum of the sensible heat and the latent heat. At atmospheric pressure, it is 1146.6 as shown in the fifth column of the table. The fourth and fifth columns of Table IV are headed Total Heat above 32°.

Q. 306—How would you calculate the total heat if you knew the temperature of the steam?

A.—Multiply the temperature by .305 and add 1082 to the product. The sum is the total heat. It will be noticed that the total heat is practically constant. It requires but 38.4 more heat units to convert a pound of water at 32° into steam of 100 pounds gage pressure than it does to convert it into steam at atmospheric pressure.

Q. 307—Calculate the total heat in steam at 14.7 pounds absolute pressure, or 0 by gage.

A.—The temperature of the steam is 212°. Then, $212 \times .305 = 64.66$; and $64.66 + 1082 = 1146.66$. This agrees with the figure given in the table.

Q. 308—Steam is at 341°. What is the total heat in 1 pound?

A.—$341 \times .305 = 104.00$. Then adding 1082, gives $104 + 1082 = 1186$. The table gives 1185.9, and the difference is imperceptible.

Q. 309—How would you calculate approximately the latent heat of steam, the temperature of the steam being known?

A.—Find the difference between the given temperature and 32°. Multiply this by .71 and subtract the result from 1092.6. The result is the latent heat, or number of heat units required to change one pound of water at the given temperature into steam at the same temperature.

Q. 310—If water is at 341°, what is the latent heat?

A.—$341 - 32 = 309$. Multiplying this by .71 gives 219.39. Then, $1092.6 - 219.39 = 873.21$, and the sixth column of Table IV gives 873.2, showing the work to be close enough.

Q. 311.—How would you find the total heat in the water at any given temperature?

A.—By subtracting the latent heat from the total heat in the steam. This gives the exact figure, but for all practical purposes the total heat in one pound of water at any given temperature may be taken as equal to the difference between temperature and 32°. (See note page 58.)

Q. 312.—What is the total heat in one pound of water at 341°?

A.—The total heat in one pound of steam at 341° is 1185.9. The latent heat at that temperature is 873.2. The difference is 312.7. The figure in the fourth column of Table IV is 312.8.

For practical purposes the total heat in the water would be taken as 341 — 32 = 309 heat-units. The error is but slightly over one per cent.

Q. 313.—How would you calculate the temperature of steam corresponding to any given pressure?

A.—If nearly exact results are desired use the formula

$$T = \frac{2038.16}{6.1003544 - \log P} - 371.85$$

where

T = temperature in degrees F.
P = absolute pressure.

This may be expressed in the following:

Rule.—To find the temperature of steam at any pressure: First, find the logarithm of the absolute pressure and subtract it from the constant 6.1003544. Second, divide the constant 2038.16 by the figure just found. Third, subtract 371.85 from the last figure obtained. The result is the temperature in degrees Fahrenheit.

Example.—At a gage pressure of 85.3 pounds the steam has a temperature of 327.75° found as follows: The absolute pressure is 14.7 pounds greater than the gage pressure or 85.3 + 14.7 = 100. The logarithm of 100 is 2. Then, 6.1003544 — 2 = 4.1003544. Dividing 2038.16 by 4.1003544 gives 699.6; and 699.6 — 371.85 = 327.75. This is with .15 of a degree or .04 per cent of the figure given in the table, the difference being negligible.

For ordinary purposes, the following formula is accurate enough:

$$T = 198.666576 \sqrt[4]{P} - 100.$$

This gives 357.92 for the temperature at 150 pounds absolute pressure, while the table gives 358.2.

The sixth root is found by taking the cube root of the square root. That is $\sqrt[6]{64} = \sqrt[3]{8} = 2$.

Q. 314—How would you calculate the pressure, if the temperature of the steam were given?

A.—The first would be by using either one of the following formulas:

$$\log P = A - \frac{B}{T} - \frac{C}{T^2}$$

where P is absolute pressure, T is the *absolute* temperature,—that is, the temperature Fahrenheit increased by 461.2°—and A, B and C are constants having the following values:

$$A = 6.1007.$$
$$\log B = 3.43642.$$
$$\log C = 5.59873.$$

EXAMPLE:—Find the pressure corresponding to a temperature of 300° F.

The absolute temperature is 300 + 461.2 = 761.2. The logarithm of 761.2 is 2.88150. Divide B by T by subtracting the logarithm of T from that of B, giving 3.43642 − 2.88150 = 0.55492. The number corresponding to this logarithm is 3.5886. Then, the logarithm of T^2 is twice that of T or $2 \times 2.8815 = 5.7630$. Subtracting this from the logarithm of C gives 5.59873 = — 1.83573 and this corresponds to the number .68507. The formula then becomes

$$\log P = 6.1007 - 3.5886 .68507 = 1.82703.$$

Then, the number coresponding to this logarithm is 67.15, the required gage pressure. In the table it will be seen that the temperature of steam at 67 pounds absolute or 52.3 pounds gage is 299.8°.

A simpler formula which is very accurate is

$$P = \left(\frac{T + 100}{177}\right)^{\frac{6}{2.638}}$$

where P = absolute pressure.
T = temperature F.

This may be expressed in the following:

Rule:—Add 100 to the given temperature in degrees Fahrenheit

and divide the sum by 177. Raise the result to the sixth power, and divide this figure by 2.038. The quotient is the absolute pressure.

EXAMPLE:—Assume a temperature of 342.5°. Find the pressure.

342.5 + 100 = 442.5. Divide 442.5 by 177, giving 2.5. Raising 2.5 to the sixth power gives 2.5 × 2.5 × 2.5 × 2.5 × 2.5 × 2.5 = 244.141. This, divided by 2.038, gives 119.8, and the table shows that the correct result is slightly over 122.

Q. 315—What is meant by the "Relative Volume of Steam," as given in the seventh column of the table?

A.—It means the volume of steam as compared with the volume of water, the latter being taken as 39° F., the point of maximum density. For example, the "Relative Volume of Steam" at atmospheric pressure, or 14.7 pounds absolute, is given in the table as 1646. That means that if any given volume of water at 39° were evaporated into steam at 14.7 pounds, the steam would occupy 1646 times as much space as the original water.

Q. 316—Give a rule for determining very closely the relative volume of steam at any given pressure.

A. *Rule:—To determine the relative volume of steam at any given pressure, find the logarithm of the absolute pressure, and multiply it by .941. Subtract the product from 4.31388. The result is the logarithm of the relative volume.*

EXAMPLE:—If steam is generated at 85.3 pounds gage, or 100 pounds absolute pressure, the relative volume is 270.3, found as follows: The log. of 100 is 2, and .941 × 2 = 1.882. Then, 4.31388 — 1.882 = 2.43188, which is the log. of 270.3.

The table gives 271.1, showing an error in the rule of less than .3 per cent.

Q. 317—How would you calculate approximately the weight of a cubic foot of steam, if the pressure were given?

A.—It could be obtained by calculating the relative volume, as in the preceding question, and then by dividing the weight of one cubic foot of water at 39° by the relative volume. This is true, because, if one cubic foot of water will make, say 300 cubic feet of steam, one cubic foot of the latter will weigh 1-300 of the weight of one cubic foot of water.

A better way is to apply the following:

Rule:—To determine very closely the density or weight per cubic foot of steam at any given pressure. Multiply the logarithm of the absolute pressure by .941 and subtract 2.519 from the result. The figure thus obtained is the logarithm of the weight per cubic foot.

EXAMPLE:—Absolute pressure 100. Density, or weight of cubic foot, .2296, found as follows:

Log. 100 = 2, and 2 × .941 = 1.882. Then, 1.882 — 2.519 = — 1.363, which is the logarithm of .2307. The last column of the table gives the weight as .2296, showing the error of the rule to be .0011 pounds or less than 1-2 of one per cent.

Q. 318—How would you calculate the volume in cubic feet of one pound of steam?

Rule:—Determine the weight per cubic foot by the preceding rule, and the reciprocal of the number (= 1 ÷ the number) is the number of cubic feet per pound of steam.

EXAMPLE:—The weight per cubic foot found in the last example was .2307. Then 1 ÷ .2307 = 4.33, the number of cubic feet in one pound of steam at 100 pounds total or absolute pressure. The eighth column of the table gives 4.36, showing but slight deviation.

Another method, which amounts to the same thing, may be summed up in the following:

Rule:—To determine the number of cubic feet in one pound of steam at any given pressure. Multiply the logarithm of the total or absolute pressure by .941 and subtract the product from 2.519. The figure thus obtained is the logarithm of the number of cubic feet in one pound of steam. The number corresponding with that logarithm in a logarithmic table is the number of cubic feet sought.

This table of Physical Properties of steam was compiled by Wm. Kent, M. E., from various sources with a few changes, as follows: The figures for temperature, total heat, and latent heat are taken, up to 210 lbs. absolute pressure, from the tables in Porter's Steam-engine Indicator, which tables have been widely accepted as standard by American engineers. The figures for total heat, given in the original as from zero F., have been changed to heat above 32° F. The figures for weight per cubic foot and for cubic feet per pound have been taken from Dwelshauvers-Dery's table, Trans. A. S. M. E., Vol. XI., as being probably more accurate than those of Porter. The figures for relative volume are from Buel's table, in Dubois's translation of Weisbach, Vol. II. They agree quite closely with the relative volumes calculated from weights as given by Dery. From 211 to 219 lbs. the figures for temperature, total heat, and latent heat are from Dery's table; and from 220 to 1000 lbs. all the figures are from Buel's table. The figures have not been carried out to as many decimal places as they are in most of the tables given by the different authorities; but any figure beyond the fourth significant figure is unnecessary in practice, and beyond the limit of error of the observations and the formulæ from which the figures are derived.

Vacuum Gauge, Inches of Mercury.	Absolute Pressure. lbs. per square inch.	Temperature Fahrenheit.	Total Heat above 32° F.		Latent Heat L. $= H - h$. Heat-units.	Relative Volume. Vol. of Water at 39° F. = 1.	Volume Cu. ft. in 1 lb. of Steam.	Weight of 1 cu ft. Steam lb.
			In the Water h Heat-units.	In the Steam H Heat-units.				
29.74	.089	32	0	1091.7	1091.7	208080	3333.3	.00030
29.67	.122	40	8	1094.1	1086.1	154330	2472.2	.00040
29.56	.176	50	18	1097.2	1079.2	107630	1724.1	.00058
29.40	.254	60	28.01	1100.2	1072.2	76370	1223.4	.00082
29.19	.359	70	38.02	1103.3	1065.3	54660	875.61	.00115
28.90	.502	80	48.04	1106.3	1058.3	39690	635.80	.00158
28.51	.692	90	58.06	1109.4	1051.3	29290	469.20	.00213
28.00	.943	100	68.08	1112.4	1044.4	21830	349.70	.00286
27.88	1	102.1	70 09	1113.1	1043.0	20623	334.23	.00299
25.85	2	126.3	94.44	1120.5	1026.0	10730	173.23	.00577
23.83	3	141.6	109.9	1125.1	1015.3	7325	117.98	.00848
21.78	4	153.1	121.4	1128.6	1007.2	5588	89.80	.01112
19.74	5	162 3	130.7	1131.4	1000.7	4530	72.50	.01373
17.70	6	170.1	138.6	1133.8	995.2	3816	61.10	.01631
15.67	7	176.9	145.4	1135.9	990.5	3302	53.00	.01887
13.63	8	182.9	151 5	1137.7	986.2	2912	46.60	.02140
11.60	9	188.3	156.9	1139.4	982.4	2607	41.82	.02391
9.56	10	193.2	161.9	1140.9	979.0	2361	37.80	.02641
7.52	11	197.8	166.5	1142.3	975.8	2159	34.61	.02889
5 49	12	202.0	170.7	1143.5	972.8	1990	31.90	.03136
3.45	13	2 5.9	174.7	1144.7	970.0	1846	29.58	.03381
1.41	14	209.6	178.4	1145.9	967.4	1721	27.50	.03625
Gauge Pressure lbs. per. sq. in.	14 7	212	180.9	1146.6	965.7	1646	26.36	.03794
0.304	15	213.0	181.9	1146.9	965.0	1614	25.87	.03868
1.3	16	216.3	185.3	1147.9	962.7	1519	24.33	.04110
2.3	17	219.4	188.4	1148.9	960 5	1434	22.98	.04352
3.3	18	222.4	191.4	1149.8	958.3	1359	21.78	.04592
4.3	19	225.2	194.3	1150.6	956.3	1292	20.70	.04831
5 3	20	227.9	197.0	1151.5	954.4	1231	19.72	.05070
6.3	21	230.5	199.7	1152.2	952.6	1176	18.84	.05308
7.3	22	233.0	202.2	1153 0	950.8	1126	18.03	.05545
8.3	23	235.4	204.7	.7	949.1	1080	17.30	.05782
9.3	24	237.8	207.0	1154.5	947.4	1038	16.62	.06018
10.3	25	240.0	209 3	1155.1	945.8	998.4	15.99	.06253
11.3	26	242.2	211.5	.8	944.3	962.3	15.42	.06487
12.3	27	244.3	213.7	1156.4	942.8	928.8	14.88	.06721
13.3	28	246 3	215.7	1157.1	941.3	897.6	14.38	.06955
143	29	248 3	217.8	.7	939.9	868.5	13.91	.07188
15.3	30	250.2	219.7	1158.3	938.9	841.3	13.48	.07420

*See note on preceding page.

Gauge Pressure, lbs. per sq. in.	Absolute Pressure, lbs. per square inch.	Temperature Fahrenheit.	Total Heat above 32° F.		Latent Heat L, $= H - h$ Heat-units.	Relative Volume Vol. of Water at 39° F. = 1.	Volume Cu. ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam lb.
			In the Water h Heat-units.	In the Steam H Heat units.				
16.3	31	252.1	221.6	.8	937.2	815.8	13.07	.07652
17.3	32	254.0	223.5	1159.4	935.9	791.8	12.68	.07884
18.3	33	255.7	225 3	.9	934.6	769.2	12 32	.08115
19.3	34	257.5	227.1	1160.5	933.4	748.0	11.98	.08346
20.3	35	259 2	228.8	1161.0	932.2	727.9	11.66	.08576
21.3	36	260.8	230.5	.5	931.0	708.8	11.36	.08806
22.3	37	262.5	232.1	1162.0	929.8	690.8	11.07	.09035
23.3	38	264.0	233 8	.5	928.7	673.7	10.79	.09264
24.3	39	265.6	235.4	.9	927.6	657.5	10.53	.09493
25.3	40	267 1	236.9	1163.4	926.5	642.0	10.28	.09721
26 3	41	268.6	238.5	.9	925.4	627.3	10.05	.09949
27.3	42	270.1	240.0	1164.3	924.4	613.3	9.83	.1018
28.3	43	271.5	241 4	.7	923.3	599.9	9.61	.1040
29.3	44	272.9	242.9	1165.2	922.3	587.0	9.41	.1063
30.3	45	274.3	244.3	.6	921.3	574.7	9.21	.1086
31.3	46	275.7	245.7	1166.0	920.4	563.0	9.02	.1108
32.3	47	277.0	247.0	.4	919.4	551.7	8.84	.1131
33.3	48	278.3	248 4	.8	918.5	540.9	8.67	.1153
34.3	49	279.6	249.7	1167.2	917.5	530.5	8.50	.1176
35.3	50	280.9	251.0	.6	916.6	520.5	8.34	.1198
36.3	51	282.1	252.2	1168.0	915.7	510.9	8.19	1221
37.3	52	283.3	253.5	.4	914.9	501.7	8.04	1243
38.3	53	284.5	254.7	.7	914.0	492.8	7.90	.1266
39.3	54	285.7	256.0	1169.1	913.1	484.2	7.76	1288
40.3	55	286.9	257.2	.4	912.3	475.9	7.63	1311
41.3	56	288.1	258.3	.8	911.5	467.9	7.50	.1333
42.3	57	289.1	259.5	1170.1	910.6	460.2	7.38	.1355
43.3	58	290.3	260.7	.5	909.8	452.7	7.26	.1377
44.3	59	291.4	261.8	.8	909.0	445.5	7.14	.1400
45.3	60	292.5	262.9	1171.2	908.2	438.5	7.03	.1422
46.3	61	293.6	264.0	.5	907.5	431.7	6.92	.1444
47.3	62	294.7	265.1	.8	906.7	425.2	6.82	.1466
48.3	63	295.7	266.2	1172.1	905.9	418.8	6.72	.1488
49.3	64	296.8	267.2	.4	905.2	412.3	6.62	.1511
50.3	65	297.8	268.3	.8	904.5	406.6	6.53	.1533
51.3	66	298.8	269.3	1173.1	903.7	400.8	6.43	.1555
52.3	67	299.8	270.4	.4	903.0	395.2	6.34	.1577
53.3	68	300.8	271.4	.7	902.3	389.8	6.25	.1599
54.3	69	301.8	272.4	1174.0	901.6	384.5	6.17	.1621
55.3	70	302.7	273.4	.3	900.9	379.3	6.09	.1643
56.3	71	303.7	274.4	.6	900.2	374.3	6.01	.1665
57.3	72	304.6	275.3	.8	899 5	369.4	5.93	.1687
58.3	73	305.6	276.3	1175.1	898.9	364.6	5.85	.1709
59.3	74	306.5	277.2	.4	898.2	360.0	5.78	.1731

Gauge Pressure, lbs. per sq. in.	Absolute Pressure, lbs. per square inch.	Temperature Fahrenheit.	Total Heat above 32° F.		Latent Heat $L = H - h$. Heat-units.	Relative Volume. Vol. of Water at 32° F. = 1.	Volume, Cu. ft. in 1 lb. of Steam.	Weight of 1 Cu. ft. Steam lb.
			In the Water h Heat-units.	In the Steam H Heat-units.				
60.3	75	307.4	278.2	.7	897.5	355.5	5.71	.1753
61.3	76	308.3	279.1	1176.0	896.9	351.1	5.63	.1775
62.3	77	309.2	280.0	.2	896.2	346.8	5.57	.1797
63.3	78	310.1	280.9	.5	895.6	342.6	5.50	.1819
64.3	79	310.9	281.8	.8	895.0	338.5	5.43	.1840
65.3	80	311.8	282.7	1177.0	894.3	334.5	5.37	.1862
66.3	81	312.7	283.6	.3	893.7	330.6	5.31	.1884
67.3	82	313.5	284.5	.6	893.1	326.8	5.25	.1906
68.3	83	314.4	285.3	.8	892.5	323.1	5.18	.1928
69.3	84	315.2	286.2	1178.1	891.9	319.5	5.13	.1950
70.3	85	316.0	287.0	.3	891.3	315.9	5.07	.1971
71.3	86	316.8	287.9	.6	890.7	312.5	5.02	.1993
72.3	87	317.7	288.7	.8	890.1	309.1	4.96	.2015
73.3	88	318.5	289.5	1179.1	889.5	305.8	4.91	.2036
74.3	89	319.3	290.4	.3	888.9	302.5	4.86	.2058
75.3	90	320.0	291.2	.6	888.4	299.4	4.81	.2080
76.3	91	320.8	292.0	.8	887.8	296.3	4.76	.2102
77.3	92	321.6	292.8	1180.0	887.2	293.2	4.71	.2123
78.3	93	322.4	293.6	.3	886.7	290.2	4.66	.2145
79.3	94	323.1	294.4	.5	886.1	287.3	4.62	.2166
80.3	95	323.9	295.1	.7	885.6	284.5	4.57	.2188
81.3	96	324.6	295.9	1181.0	885.0	281.7	4.53	.2210
82.3	97	325.4	296.7	.2	884.5	279.0	4.48	.2231
83.3	98	326.1	297.4	.4	884.0	276.3	4.44	.2253
84.3	99	326.8	298.2	.6	883.4	273.7	4.40	.2274
85.3	100	327.6	298.9	.8	882.9	271.1	4.36	.2296
86.3	101	328.3	299.7	1182.1	882.4	268.5	4.32	.2317
87.3	102	329.0	300.4	.3	881.9	266.0	4.28	.2339
88.3	103	329.7	301.1	.5	881.4	263.6	4.24	.2360
89.3	104	330.4	301.9	.7	880.8	261.2	4.20	.2382
90.3	105	331.1	302.6	.9	880.3	258.9	4.16	.2403
91.3	106	331.8	303.3	1183.1	879.8	256.6	4.12	.2425
92.3	107	332.5	304.0	.4	879.3	254.3	4.09	.2446
93.3	108	333.2	304.7	.6	878.8	252.1	4.05	.2467
94.3	109	333.9	305.4	.8	878.3	249.9	4.02	.2489
95.3	110	334.5	306.1	1184.0	877.9	247.8	3.98	.2510
96.3	111	335.2	306.8	.2	877.4	245.7	3.95	.2531
97.3	112	335.9	307.5	.4	876.9	243.6	3.92	.2553
98.3	113	336.5	308.2	.6	876.4	241.6	3.88	.2574
99.3	114	337.2	308.8	.8	875.9	239.6	3.85	.2596
100.3	115	337.8	309.5	1185.0	875.5	237.6	3.82	.2617
101.3	116	338.5	310.2	.2	875.0	235.7	3.79	.2638
102.3	117	339.1	310.8	.4	874.5	233.8	3.76	.2660

Gauge Pressure, lbs. per sq. in.	Absolute Pressure, lbs. per square inch.	Temperature Fahrenheit.	Total Heat above 32° F.		Latent Heat $L = H - h$. Heat-units.	Relative Volume. Vol. of water at 39.°1 F. = 1.	Volume Cu. ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam, lb.
			In the Water h Heat-units.	In the Steam H Heat-units.				
103.3	118	339.7	311.5	.6	874.1	231.9	3.73	.2681
104.3	119	340.4	312.1	.8	873.6	230.1	3.70	.2703
105.3	120	341.0	312.8	.9	873.2	228.3	3.67	.2724
106.3	121	341.6	313.4	1186.1	872.7	226.5	3.64	.2745
107.3	122	342.2	314.1	.3	872.3	224.7	3.62	.2766
108.3	123	342.9	314.7	.5	871.8	223.0	3.59	.2788
109.3	124	343.5	315.3	.7	871.4	221.3	3.56	.2809
110.3	125	344.1	316.0	.9	870.9	219.6	3.53	.2830
111.3	126	344.7	316.6	1187.1	870.5	218.0	3.51	.2851
112.3	127	345.3	317.2	.3	870.0	216.4	3.48	.2872
113.3	128	345.9	317.8	.4	869.6	214.8	3.46	.2894
114.3	129	346.5	318.4	.6	869.2	213.2	3.43	.2915
115.3	130	347.1	319.1	.8	868.7	211.6	3.41	.2936
116.3	131	347.6	319.7	1188.0	868.3	210.1	3.38	.2957
117.3	132	348.2	320.3	.2	867.9	208.6	3.36	.2978
118.3	133	348.8	320.8	.3	867.5	207.1	3.33	.3000
119.3	134	349.4	321.5	.5	867.0	205.7	3.31	.3021
120.3	135	350.0	322.1	.7	866.6	204.2	3.29	.3042
121.3	136	350.5	322.6	.9	866.2	202.8	3.27	.3063
122.3	137	351.1	323.2	1189.0	865.8	201.4	3.24	.3084
123.3	138	351.8	323.8	.2	865.4	200.0	3.22	.3105
124.3	139	352.2	324.4	.4	865.0	198.7	3.20	.3126
125.3	140	352.8	325.0	.5	864.6	197.3	3.18	.3147
126.3	141	353.3	325.5	.7	864.2	196.0	3.16	.3169
127.3	142	353.9	326.1	.9	863.8	194.7	3.14	3190
128.3	143	354.4	326.7	1190.0	863.4	193.4	3.11	.3211
129.3	144	355.0	327.2	.2	863.0	192.2	3.09	.3232
130.3	145	355.5	327.8	.4	862.6	190.9	3.07	.3253
131.3	146	356.0	328.4	.5	862.2	189.7	3.05	.3274
132.3	147	356.6	328.9	.7	861.8	185.5	3.04	.3295
133.3	148	357.1	329.5	.9	861.4	187.3	3.02	.3316
134.3	149	357.6	330.0	1191.0	861.0	186.1	3.00	.3337
135.3	150	358.2	330.6	.2	860.6	184.9	2.98	.3358
136.3	151	358.7	331.1	.3	860.2	183.7	2.96	.3379
137.3	152	359.2	331.6	.5	859.9	182.6	2.94	.3400
138.3	153	359.7	332.2	.7	859.5	181.5	2.92	.3421
139.3	154	360.2	332.7	.8	859.1	180.4	2.91	.3442
140.3	155	360.7	333.2	1192.0	858.7	179.2	2.89	.3463
141.3	156	361.3	333.8	.1	858.4	178.1	2.87	.3483
142.3	157	361.8	334.3	.3	858.0	177.0	2.85	.3504
143.3	158	362.3	334.8	.4	857.6	175.0	2.84	.3525
144.3	159	362.8	335.3	.6	857.2	174.9	2.82	.3546
145.3	160	363.3	335.9	.7	856.9	173.9	2.80	.3567

Gauge Pressure, lbs. per. sq. in.	Absolute Pressure, lbs. per. square inch.	Temperature Fahrenheit.	Total Heat above 32° F.		Latent Heat $L. = H - h$ Heat-units.	Relative Volume Vol. of Water at 39° F. = 1.	Volume Cu. ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam lb.
			In the Water h Heat-units.	In the Steam H Heat-units.				
146.3	161	363.8	336.4	.9	856.5	172.9	2.79	.3588
147.3	162	364.3	336.9	1193.0	856.1	171.9	2.77	.3609
148.3	163	364.8	337.4	.2	855.8	171.0	2.76	.3630
149.3	164	365.3	337.9	.3	855.4	170.0	2.74	.3650
150.3	165	365.7	338.4	.5	855.1	169.0	2.72	.3671
151.3	166	366.2	338.9	.6	854.7	168.1	2.71	.3692
152.3	167	366.7	339.4	.8	854.4	167.1	2.69	.3713
153.3	168	367.2	339.9	.9	854.0	166.2	2.68	.3734
154.3	169	367.7	340.4	1194.1	853.6	165.3	2.66	.3754
155.3	170	368.2	340.9	.2	853.3	164.3	2.65	.3775
156.3	171	368.6	341.4	.4	852.9	163.4	2.63	.3796
157.3	172	369.1	341.9	.5	852.6	162.5	2.62	.3817
158.3	173	369.6	342.4	.7	852.3	161.6	2.61	.3838
159.3	174	370.0	342.9	.8	851.9	160.7	2.59	.3858
160.3	175	370.5	343.4	.9	851.6	159.8	2.58	.3879
161.3	176	371.0	343.9	1195.1	851.2	158.9	2.56	.3900
162.3	177	371.4	344.3	.2	850.9	158.1	2.55	.3921
163.3	178	371.9	344.8	.4	850.5	157.2	2.54	.3942
164.3	179	372.4	345.3	.5	850.2	156.4	2.52	.3962
165.3	180	372.8	345.8	.7	849.9	155.6	2.51	.3983
166.3	181	373.3	346.3	.8	849.5	154.8	2.50	.4004
167.3	182	373.7	346.7	.9	849.2	154.0	2.48	.4025
168.3	183	374.2	347.2	.1	848.9	153.2	2.47	.4046
169.3	184	374.6	347.7	1196.2	848.5	152.4	2.46	.4066
170.3	185	375.1	348.1	.3	848.2	151.6	2.45	.4087
171.3	186	375.5	348.6	.5	847.9	150.8	2.43	.4108
172.3	187	375.9	349.1	.6	847.6	150.0	2.42	.4129
173.3	188	376.4	349.5	.7	847.2	149.2	2.41	.4150
174.3	189	376.9	350.0	.9	846.9	148.5	2.40	.4170
175.3	190	377.3	350.4	1197.0	846.6	147.8	2.39	.4191
176.3	191	377.7	350.9	.1	846.3	147.0	2.37	.4212
177.3	192	378.2	351.3	.3	845.9	146.3	2.36	.4233
178.3	193	378.6	351.8	.4	845.6	145.6	2.35	.4254
179.3	194	379.0	352.2	.5	845.3	144.9	2.34	.4275
180.3	195	379.5	352.7	.7	845.0	144.2	2.33	.4296
181.3	196	380.0	353.1	.8	844.7	143.5	2.32	.4317
182.3	197	380.3	353.6	.9	844.4	142.8	2.31	.4337
183.3	198	380.7	354.0	1198.1	844.1	142.1	2.29	.4358
184.3	199	381.2	354.4	.2	843.7	141.4	2.28	.4379
185.3	200	381.6	354.9	.3	843.4	140.8	2.27	.4400
186.3	201	382.0	355.3	.4	843.1	140.1	2.26	.4420
187.3	202	382.4	355.8	.6	842.8	139.5	2.25	.4441
188.3	203	382.8	356.2	.7	842.5	138.8	2.24	.4462

Gauge Pressure, lbs. per sq. in.	Absolute Pressure, lbs. per square inch.	Temperature Fahrenheit.	Total Heat above 32° F.		Latent Heat $L. = H - h$. Heat-units.	Relative Volume. Vol. of water at 39° F. = 1.	Volume Cu. ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam, lb.
			In the Water h Heat-units.	In the Steam H Heat-units.				
189.3	204	383.2	356.6	.8	842.2	138.1	2.23	.4482
190.3	205	383.7	357.1	1199.0	841.9	137.5	2.22	.4503
191.3	206	384.1	357.5	.1	841.6	136.9	2.21	.4523
192.3	207	384.5	357.9	.2	841.3	136.3	2.20	.4544
193.3	208	384.9	358.3	.3	841.0	135.7	2.19	.4564
194.3	209	385.3	358.8	.5	840.7	135.1	2.18	.4585
195.3	210	385.7	359.2	.6	840.4	134.5	2.17	.4605
196.3	211	386.1	359.6	.7	840.1	133.9	2.16	.4626
197.3	212	386.5	360.0	.8	839.8	133.3	2.15	.4646
198.3	213	386.9	360.4	.9	839.5	132.7	2.14	.4667
199.3	214	387.3	360.9	1200.1	839.2	132.1	2.13	.4687
200.3	215	387.7	361.3	.2	838.9	131.5	2.12	.4707
201.3	216	388.1	361.7	.3	838.6	130.9	2.12	.4728
202.3	217	388.5	362.1	.4	838.3	130.3	2.11	.4748
203.3	218	388.9	362.5	.6	838.1	129.7	2.10	.4768
204.3	219	389.3	362.9	.7	837.8	129.2	2.09	.4788
205.3	220	389.7	362.2*	1200.8	838.6*	128.7	2.06	.4852
215.3	230	393.6	366.2	1202.0	835.8	123.3	1.98	.5061
225.3	240	397.3	370.0	1203.1	833.1	118.5	1.90	.5270
235.3	250	400.9	373.8	1204.2	830.5	114.0	1.83	.5478
245.3	260	404.4	377.4	1205.3	827.9	109.8	1.76	.5686
255.3	270	407.8	380.9	1206.3	825.4	105.9	1.70	.5894
265.3	280	411.0	384.3	1207.3	823.0	102.3	1.64	.6101
275.3	290	414.2	387.7	1208.3	820.6	99.0	1.585	.6308
285.3	300	417.4	390.9	1209.2	818.3	95.8	1.535	.6515
335.3	350	432.0	406.3	1213.7	807.5	82.7	1.325	.7545
385.3	400	444.9	419.8	1217.7	797.9	72.8	1.167	.8572
435.3	450	456.6	432.2	1221.3	789.1	65.1	1.042	.9595
485.3	500	467.4	443.5	1224.5	781.0	58.8	.942	1.062
535.3	550	477.5	454.1	1227.6	773.5	53.6	.859	1.164
585.3	600	486.9	464.2	1230.5	766.3	49.3	.790	1.266
635.3	650	495.7	473.6	1233.2	759.6	45.6	.731	1.368
685.3	700	504.1	482.4	1235.7	753.3	42.4	.680	1.470
735.3	750	512.1	490.9	1238.0	747.2	39.6	.636	1.572
785.3	800	519.6	498.9	1240.3	741.4	37.1	.597	1.674
835.3	850	526.8	506.7	1242.5	735.8	34.9	.563	1.776
885.3	900	533.7	514.0	1244.7	730.6	33.0	.532	1.878
935.3	950	540.3	521.3	1246.7	725.4	31.4	.505	1.980
985.3	1000	546.8	528.3	1248.7	720.3	30.0	.480	2.082

*The discrepancies at 205.3 lbs. gauge are due to the change from Dery's to Buel's figures.

SECTION VI.

Combustion and Firing. — Heating Feed-Water.

Q. 319 —What are the principal fuels used in boiler practice?

A.—Coal, wood and oil.

Q. 320 —What are the two principal kinds of coal?

A.—Anthracite and bituminous.

Q. 321 —What are the characteristics of anthracite?

A.—It is hard and compact, with a shiny surface when first broken; contains little hydrogen and volatile matter, but consists almost entirely of carbon and ash-making impurities. It ignites with difficulty and burns with a short, clear flame, and with little smoke.

Q. 322 —What are the characteristics of bituminous coal?

A.—Bituminous coal is soft, crumbles easily with handling, has a dull fracture, contains a large proportion of hydrogen and volatile matter, ignites readily, burns with a long yellow flame, and produces a great deal of smoke unless properly dealt with.

Q. 323 —What is combustion?

A.—The union of the carbon and hydrogen of the fuel with oxygen.

Q. 324 —Where does the oxygen come from?

A.—From the air.

Q. 325 —Of what is air composed?

A.—Oxygen and nitrogen.

Q. 326 —In what proportions?

A.—By volume, about 79 per cent of nitrogen and 21 per cent of oxygen. By weight, about 77 per cent nitrogen and 23 per cent oxygen.

Q. 327—Do these elements form a chemical combination?
A.—No; simply a mechanical mixture, the proportions varying slightly according to location and the purity of the atmosphere.

Q. 328—How many pounds of air are required to furnish one pound of oxygen when the oxygen is 23 per cent of the total weight?
A.—100 ÷ 23 = 4.4, about.

Q. 329—What becomes of carbon when it is burned?
A.—Each atom of carbon combines with two atoms of oxygen, and the vibration set up by their combination is what we know as heat.

Q. 330—Is any matter destroyed in the process of combustion?
A.—No; it is just as impossible to destroy an atom of matter as to create one. The carbon and oxygen combined form carbonic acid gas, which passes off through the stack, and the weight of carbonic acid gas sent off is just equal to the combined weight of the carbon and oxygen consumed in combustion.

Q. 331—How many pounds of oxygen are required for the perfect combustion of one pound of carbon?
A.—2.66 pounds.

Q. 332—What other name is given to this carbonic acid gas?
A.—It is called carbon dioxide, the prefix *di* meaning "two," the name thus implying two atoms of oxygen and one of carbon.

Q. 333—How many heat-units are generated by the complete combustion of one pound of carbon?
A.—About 14,500.

Q. 334—If there is not enough oxygen present to furnish two atoms for each atom of carbon, what will happen?
A.—Some of the atoms of carbon will combine with only one atom of oxygen, forming carbonic oxide gas.

Q. 335—What other name is given to this gas?
A.—It is called carbon monoxide, the prefix *mon* meaning "one."

Q. 336—How many heat-units would be generated by this imperfect combustion of a pound of carbon into carbonic oxide?

A.—About 4,400 units, or less than one-third as much as when the combustion is perfect.

Q. 337—How is this imperfect combustion guarded against in practice?

A.—By admitting air in excess of that chemically required for the combustion of the fuel, as, if only the number of atoms of oxygen chemically required were admitted, it would be impossible to insure that each should meet its atom of carbon before the temperature was reduced below that of ignition.

Q. 338—What is the disadvantage of admitting this excess of air?

A.—The surplus air has to be heated up to the furnace temperature without adding anything to the combustion, and carries off to the chimney as many units of heat as are required to raise it from the temperature at which it enters the furnace to that at which it enters the uptake. It requires the utmost nicety of judgment and observation on the part of the fireman to determine when the loss from this cause equals that from incomplete combustion.

Q. 339—How many heat-units are required to raise one pound of air through one degree Fahrenheit, when it is free to expand?

A.—.2375 of a heat-unit.

Q. 340—We have seen (Q. 328) that it requires about 4.5 pounds of air to furnish one pound of oxygen, and (Q. 331) 2.66 pounds of oxygen for the combustion of one pound of carbon. How many pounds of air then would be required to furnish the oxygen chemically required for the combustion of one pound of carbon?

A.—$2.66 \times 4.5 =$ about 12.

Q. 341—Suppose twice this amount of air was admitted at 70 degrees, what would be the number of heat-units carried to the chimney from each pound of combustible by the surplus air, assuming the uptake temperature to be 600 degrees?

A.—$12 \times .23751 \times (600 - 70) = 1511$.

Q. 342—What percentage is this of the heat-units generated by the complete combustion of the carbon?

A.—$1511 \div 14{,}500 \times 100 =$ over ten per cent.

Q. 343—How many pounds of water would be evaporated per pound of carbon (neglecting losses by radiation, etc.) if an excess of 50 per cent of air at 60 degrees was admitted and the flue temperature was 560 degrees?

A.—Each pound of carbon would require 2.66 pounds of oxygen (Q. 331) or about 12 pounds of air (Q. 340). The oxygen would combine with the carbon to form 3.66 pounds of carbonic acid gas, and leave 9.34 pounds of nitrogen. There would also be 50 per cent of 12 = 6 pounds of air, of which 1.33 pounds would be oxygen and 4.67 pounds nitrogen. The flue gases would then consist of

Carbonic acid	3.66 lbs.
Nitrogen 9.34 + 4.67 =	14.01 lbs.
Oxygen	1.33 lbs.
	19.00 lbs.

or the 1 pound of carbon and 18 pounds of air. Multiplying each by its specific heat, i. e., the quantity of heat required to raise one pound one degree, we get the heat-units necessary to raise the gas through one degree, as follows:

	Lbs.		Specific Heat.		Heat-units per degree.
Carbonic acid	3.66	×	.2170	=	.794220
Nitrogen	14.01	×	.2438	=	3.415638
Oxygen	1.33	×	.2175	=	.289275
					4.499133

It would, then, require to heat this 19 pounds of gas 4.5 heat-units for each degree of difference between the temperature at which the air goes into the furnace and that at which it leaves the chimney; or in this case, 560 — 60 = 500 degrees difference. Then 500 × 4.5 = 2,250 heat units or

$$\frac{2250}{14,500} \times 100 = 15.5$$

per cent of the heat generated by the combustion of the carbon is carried off by the heated products of combustion. There are left, therefore, 14,500 — 2,250 = 12,250 heat units available for the evaporation of water; and as it takes 965.7 heat-units to evaporate one pound of water from feed-water at 212° into steam at 14.7 pounds absolute (Table IV) the water evaporated would be 12,250 ÷ 965.7 = nearly 12.7 pounds of water. This is called the evaporation "from and at 212°" because the evaporation is from water at 212° into steam at the same temperature.

Q. 344.—What other valuable constituent does coal contain?
A.—Hydrogen.

Q. 345.—What takes place when hydrogen is burned?

A.—Two atoms of hydrogen combine with one atom of oxygen, producing an intense heat by their combination.

Q. 346—What is the product of combustion of hydrogen, i. e., what do the hydrogen and oxygen form by their combination?

A.—Water.

Q. 347—How many heat units are generated by the combustion of one pound of hydrogen?

A.—About 62,000.

Q. 348—How many pounds of oxygen are required for the combustion of one pound of hydrogen?

A.—Eight pounds.

Q. 349—So that the combustion of one pound of hydrogen will make nine pounds of water?

A.—Yes.

Q. 350—Since water consists of oxygen and hydrogen, and hydrogen is so valuable as a fuel, why not decompose water into its elements, and burn the hydrogen, using the oxygen for the purpose, and avoid heating a surplus of air, inert nitrogen, etc.?

A.—Because it takes just as much heat or force or power to decompose the water as the hydrogen would give by its combustion. If we raise a weight from the earth against the attraction of gravity we put into it the power of doing work in its descent just equal to the amount of work required to raise it. So in separating the atoms of oxygen from those of hydrogen in water, or of carbon in carbonic acid, we put into them a power of doing work (i. e., generating heat by coming together) just equal to the amount of work which is consumed in their dissociation.

Q. 351—Does the carbonic acid which is discharged by tons from the furnaces of locomotives and manufactories have any permanent effect upon the composition of the atmosphere?

A.—No. Analyses of the atmosphere made years apart show no appreciable difference.

Q. 352—What becomes of the carbonic acid?

A.—It is decomposed by the plants. The dissociation so difficult in the laboratory goes on quietly and naturally in the vegetable cell under the influence of the sunlight. The plant appropriates the carbon and builds it up into its own structure, and sets the oxygen free in the atmosphere. When the plant is burned, or eaten (for animals live by combustion), the

carbon and oxygen again combine to go again through the same process.

Q. 353—What kind of coal contains the most hydrogen?

A.—Bituminous. Anthracite coal contains a very small percentage.

Q. 354—What other matter is ordinarily found in coal?

A.—Water, absorbed as moisture, nitrogen, sulphur in small proportions, and more or less slate and earthy material.

Q. 355—What is the method of burning of anthracite coal?

A.—It ignites with difficulty, requiring a high temperature and good draft, gives off little smoke and flame, but burns mostly as an incandescent mass, crumbling as the process of combustion goes on, and leaving its incombustible impurities in a fine pulverulent ash, except where they have been melted and run together in clinker. It lights slowly, and does not give off a large amount of gas and volatile matter on its first contact with the fire; and the distillation being more gradual, a large amount of air is not required immediately after firing.

Q. 356—How does bituminous coal act in combustion?

A.—Bituminous coal has a large amount of volatile matter, which is thrown off as soon as it feels the heat of the furnace. It flashes into flame as though it had been sprinkled with petroleum. During this stage of the combustion a great deal of air is required to furnish the oxygen for so large an amount of combustible gas; and it is difficult to get the oxygen in fast enough without cooling the gases below the point of ignition. It is for this reason that furnaces fired with soft coal smoke so badly, especially right after firing. As these volatile products are given off the coal swells and forms a spongy coke, the carbon of which is more gradually distilled.

Q. 357—What is the best method of handling a soft coal fire?

A.—A portion of the fire should be kept bright and comparatively open, in order to furnish the heat and air necessary to burn the gases from the freshly fired fuel. This is perhaps best done by firing the fresh coal in the front of the furnace so that the gas passes over the hot fire in the back part, admitting at the same time enough air above the fire to furnish the oxygen for its combustion. You cannot depend here upon the air which comes through the bed of fuel upon the grates, for each two atoms of oxygen will have com-

bined with their atom of carbon, unless the fire is very thin; and unless more oxygen is present another atom of carbon will catch on, making carbonic oxide instead of carbonic acid, with a greatly decreased amount of heat. After the volatile matter has passed off, push back the lighted coke to replenish the back end of the fire, and repeat the process. Several methods are in vogue for introducing heated air into the furnace and combustion chamber through the bridge wall and side walls, usually with beneficial results with soft coal.

Q. 358—What other method is practiced for promoting the combustion of the volatile portions of the fuel?

A.—Firing one side of the furnace at a time, having always one side bright to maintain the temperature and ignite the gases distilled from the fresh coal.

Q. 359—Is the admission of air above the fire through the bridge wall and side-walls desirable?

A.—With bituminous coals it both reduces smoke and increases economy. With anthracite coal it is of no advantage.

Q. 360—What does smoke indicate?

A.—Imperfect combustion.

Q. 361—Is absence of smoke proof positive of perfect combustion?

A.—No; unconsumed gas may be escaping.

Q. 362—What is done when the boilers are to be inactive for some time, but it is desired to keep the fire over during the period?

A.—The fires are banked.

Q. 363—Describe the operation of banking.

A.—There are two general methods which may be pursued. One is clean the fire thoroughly, and pile what remains against the bridge-wall, on the back half of the grates, leaving the front part bare. Fresh coal is then charged in a thick layer over the banked fuel, and the fire is left with the ash-pit doors closed, the fire-door open, and the damper either nearly or entirely closed. The closure of the ash-pit and the access of cold air above the fire make the ignition of the bank of fresh coal very slow, so that several hours will elapse before it is ignited, and even then it burns slowly and not actively. At the end of the time, determined by the quantity of fresh coal

used in banking, the fire is again cleaned. Then it is spread over the grates and is ready for another run.

Another method, that of banking flat, is to leave the fire, after cleaning, spread out evenly over the grate, and then cover over with a layer of fresh fuel.

Q. 364—Do these methods of banking apply to both anthracite and bituminous coal?

A.—Yes.

Q. 365—How should a wood fire be left?

A.—The dampers should all be closed as tight as possible except the one in the flue leading to the chimney; if there is one there it should be closed just enough so that the furnace will not smoke. If the dampers below the grate are in poor condition, so that they will leak air, they should be banked with ashes. The main idea is to keep all air out of the furnace.

Q. 366—Why is everything closed with a wood fire, and the door left open with a coal fire?

A.—Because wood burns more readily, and if air could gain access to it from the top it would be apt to burn up and perhaps raise steam to the blowing-off point. With coal, the heat of the glowing mass is such that it will draw the air through the lower dampers, if they are open at all, to such an extent that the fire will burn out; and if these dampers are closed, the coal does not have staying qualities to remain glowing for a long time in ordinary furnaces. Therefore, the lower dampers are allowed to leak air enough to keep the fire burning, and the draft is tempered by opening the furnace door.

Q. 367—Describe the process of cleaning a fire.

A.—Four tools are used in cleaning the grate. These are a long straight bar known as a slice-bar, a similar bar with a point bent at right angles to make a hook, a hoe, a long handled rake with three or four prongs. The hook may be run along between the grate bars from below, to clear the spaces from ashes and clinkers. The slice-bar is thrust under the fire on top of the grate to break up the cinder; it is also used to stir and break up caking coals. The rake is used to haul the fire forward or to draw out cinders.

To clean a fire, break up the cinder with the slice-bar, and thrown down the ashes; if necessary, work the fire back toward the bridge and expose the grate in front, which may then be thoroughly cleaned. Then haul the fire forward and clean the back end of the furnace, pulling out through the fire door

clinkers which will not break up and pass through the grate. If it is preferred, one side of the grate may be cleaned at a time.

Before cleaning, the fire should be allowed to burn down rather low, leaving enough glowing coal to give a good start to a new fire, and the draught should be checked before the grate is cleaned.

After cleaning, the coals are spread evenly, and fresh coal is fired.

Q. 368.—What may be said to be the standard type of shell boiler in American stationary practice?

A.—The horizontal return tubular.

Q. 369.—How much grate surface should such a boiler have in proportion to its heating-surface for anthracite coal?

A.—"A ratio of 36 to 1 (i. e., 36 square feet of heating-surface to 1 of grate) provides a sufficient quantity of heating-surface to secure the full efficiency of anthracite coal where the rate of combustion is not more than 12 pounds per square foot of grate per hour."—[*Barrus.*]

Q. 370.—Does bituminous coal require more heating-surface or less in proportion to the grate than anthracite?

A.—More.

Q. 371.—Explain why.

A.—Anthracite coal makes a hot local fire with little flame, and a limit to the value of additional tube-surface is soon reached. Bituminous coal is gaseous, the combustion is widespread, and the tube-surface more valuable. Bituminous coal also makes more soot, which reduces the efficiency of the absorbing surfaces, allowing more to be used to advantage.

Q. 372.—What is the proper ratio for bituminous coal when the rate of combustion is 10 or 12 pounds per square foot of grate?

A.—45 to 50.

Q. 373.—How many pounds of coal are burned in practice on a square foot of grate with natural draft?

A.—From 5 to 25, ordinarily from 10 to 15.

Q. 374.—Is slow or quick combustion most favorable to economy?

A.—Quick combustion and high furnace temperature, provided sufficient heating-surface is provided to absorb the heat of the fuel as fast as it is burned.

Q. 375.—How many pounds of water could be evaporated

by the combustion of one pound of pure carbon if all the heat were utilized for this purpose, and why?

A.—If it takes 965.7 heat-units to evaporate one pound of water from and at 212°, 14,500 heat-units would evaporate 14,500 ÷ 965.7 = 15 pounds.

Q. 376—How nearly is this approached in practice?

A.—With anthracite coal, which is nearest to pure carbon, numerous tests show between 11 and 12 pounds of water evaporated from and at 212° per pound of combustible; 11 1-4 pounds would be just 75 per cent of the theoretical; 12 pounds 80 per cent.

Q. 377—What becomes of the other 20 or 25 per cent?

A.—Either the heats fails to be generated, through imperfect combustion, or is carried off in the products of combustion and by radiation.

Q. 378—How may the loss from radiation be kept at a minimum?

A.—Radiation may be retarded by covering all exposed portions of the boiler with non-conducting material, and the heat unavoidably radiated may be partially restored by drawing the air supply for the furnace from the heated space above the boiler.

Q. 379—How may the rejected heat be reduced to a minimum?

A.—By providing sufficient heating surface, and so regulating the firing that the escaping gases shall be reduced to the lowest possible temperature; while maintaining a high rate of combustion, to admit no more air than is necessary to secure the complete combustion of the fuel and to prevent the leakage of air into the setting through walls, back-connections, etc.

Q. 380—What should be the limit of temperature for the escaping gases?

A.—For anthracite, 375°; for Cumberland coal, 415° (Barrus).

Q. 381—How may the temperature of the escaping gases be further reduced?

A.—By passing them through "economizers" and heaters, wherein a portion of their heat is imparted to the feed-water or air supply.

Q. 382—What per cent of saving is effected by heating the feed-water a given amount?

A.—About one per cent for every eleven degrees increase in temperature, or one-eleventh of one per cent for each degree. The saving is a little more than this with high initial temperatures of feed and low pressures, and somewhat less with low initial temperatures of feed and high pressures. This is exhibited in Table V, which gives the percentage of saving for each degree of increase in temperature with various initial temperatures and pressures.

Q. 383—Give a rule for finding the saving which may be expected by heating the feed a given amount.

A.—*Rule:—Divide the difference in the total heat of the water above 32° before and after heating by the total heat required to convert it into steam from the initial temperature. Multiply the quotient by 100 and the product will be the percentage of saving to be expected.*

EXAMPLE:—What percentage of saving in fuel may be expected from heating feed-water from 60° to 140° for a boiler carrying 80 pounds?

OPERATION:—

Water at 140° contains, above 32°	108.25	heat-units
" " 60° " " "	28.01	" "
There has been added the difference	80.24	" "

There are in a pound of steam of 80 pounds gage pressure 1,180.7 heat-units above 32°, or 1,180.7 — 28.01 = 1,152.69 above 60°. This is the amount of heat which the boiler would have to supply to make a pound of steam from the given initial temperature, 60°; but we have seen that in raising the water to 140°, 80.24 units are supplied by the heater, thus saving $\frac{80.24}{1,152.69}$ of the heat required, or

$$\frac{80.24 \times 100}{1,152.69} = 6.94 \text{ per cent.}$$

The same result may be found from Table V. By looking in the line corresponding with 60° initial temperature and under 80 pounds pressure it will be seen that each degree of increase in temperature will effect a saving of .0867 per cent. An increase of 140 — 60 = 80° will therefore effect a saving of 80 × .0867 = 6.936 per cent.

Q. 384—Does this apply when the increase in temperature comes from the use of an ordinary injector?

A.—No, for the steam by which the water is heated is furnished from the boiler itself. It does apply, however, to the

Initial Temperature F°	GAGE PRESSURE OF STEAM.									
	0	5	10	15	20	25	30	35	40	45
32	0.0872	0.0868	0.0866	0.0863	0.0861	0.0859	0.0858	0.0856	0.0855	0.0854
35	0.0874	0.0871	0.0868	0.0866	0.0864	0.0862	0.0860	0.0859	0.0857	0.0856
40	0.0878	0.0875	0.0872	0.0869	0.0867	0.0865	0.0864	0.0862	0.0861	0.0860
45	0.0882	0.0878	0.0876	0.0873	0.0871	0.0869	0.0868	0.0866	0.0865	0.0863
50	0.0886	0.0882	0.0879	0.0877	0.0875	0.0873	0.0871	0.0870	0.0868	0.0867
55	0.0890	0.0886	0.0883	0.0881	0.0878	0.0877	0.0875	0.0874	0.0872	0.0871
60	0.0894	0.0890	0.0887	0.0885	0.0883	0.0881	0.0879	0.0877	0.0876	0.0875
65	0.0898	0.0894	0.0891	0.0889	0.0887	0.0885	0.0883	0.0881	0.0880	0.0879
70	0.0902	0.0898	0.0896	0.0893	0.0890	0.0889	0.0887	0.0885	0.0884	0.0882
75	0.0906	0.0902	0.0899	0.0897	0.0894	0.0893	0.0891	0.0889	0.0888	0.0886
80	0.0910	0.0906	0.0903	0.0901	0.0898	0.0897	0.0895	0.0893	0.0891	0.0890
85	0.0914	0.0910	0.0907	0.0905	0.0902	0.0901	0.0899	0.0897	0.0896	0.0894
90	0.0919	0.0914	0.0911	0.0909	0.0907	0.0905	0.0903	0.0901	0.0900	0.0898
95	0.0923	0.0919	0.0916	0.0913	0.0911	0.0909	0.0907	0.0905	0.0904	0.0902
100	0.0927	0.0923	0.0920	0.0917	0.0915	0.0913	0.0911	0.0909	0.0908	0.0906
105	0.0931	0.0927	0.0924	0.0921	0.0919	0.0917	0.0915	0.0913	0.0912	0.0910
110	0.0936	0.0931	0.0728	0.0926	0.0923	0.0921	0.0919	0.0918	0.0916	0.0915
115	0.0940	0.0936	0.0933	0.0930	0.0928	0.0925	0.0924	0.0922	0.0920	0.0919
120	0.0945	0.0940	0.0937	0.0934	0.0932	0.0930	0.0928	0.0926	0.0925	0.0923
125	0.0949	0.0945	0.0942	0.0939	0.0936	0.0934	0.0932	0.0931	0.0929	0.0927
130	0.0954	0.0949	0.0946	0.0943	0.0941	0.0939	0.0937	0.0935	0.0934	0.0932
135	0.0958	0.0954	0.0951	0.0948	0.0945	0.0943	0.0941	0.0939	0.0938	0.0936
140	0.0963	0.0958	0.0955	0.0952	0.0950	0.0948	0.0946	0.0943	0.0943	0.0941
145	0.0968	0.0963	0.0960	0.0957	0.0954	0.0952	0.0950	0.0948	0.0947	0.0945
150	0.0975	0.0968	0.0964	0.0961	0.0959	0.0957	0.0955	0.0953	0.0951	0.0947
155	0.0979	0.0973	0.0969	0.0966	0.0964	0.0961	0.0960	0.0957	0.0956	0.0954
160	0.0982	0.0977	0.0974	0.0971	0.0968	0.0966	0.0964	0.0962	0.0961	0.0959
165	0.0987	0.0982	0.0979	0.0976	0.0973	0.0971	0.0969	0.0967	0.0965	0.0963
170	0.0992	0.0987	0.0984	0.0980	0.0978	0.0976	0.0974	0.0972	0.0970	0.0968
175	0.0997	0.0994	0.0989	0.0985	0.0983	0.0980	0.0979	0.0976	0.0975	0.0973
180	0.1002	0.0997	0.0993	0.0990	0.0988	0.0985	0.0983	0.0981	0.0981	0.0978
185	0.1007	0.1004	0.0998	0.0995	0.0993	0.0990	0.0988	0.0986	0.0985	0.0983
190	0.1012	0.1007	0.1004	0.1000	0.0998	0.0995	0.0993	0.0991	0.0989	0.0987
195	0.1017	0.1012	0.1009	0.1005	0.1003	0.1000	0.0998	0.0996	0.0994	0.0993
200	0.1022	0.1018	0.1014	0.1010	0.1008	0.1005	0.1003	0.1000	0.0999	0.0997
205	0.1027	0.1023	0.1019	0.1015	0.1013	0.1010	0.1008	0.1006	0.1004	0.1003
210	0.1033	0.1028	0.1024	0.1020	0.1018	0.1015	0.1013	0.1011	0.1009	0.1007
212		0.1030	0.1026	0.1023	0.1020	0.1017	0.1015	0.1013	0.1011	0.1010
215		0.1033	0.1029	0.1026	0.1024	0.1020	0.1018	0.1016	0.1014	0.1012
220		0.1039	0.1035	0.1031	0.1029	0.1026	0.1024	0.1021	0.1019	0.1018
225		0.1044	0.1040	0.1036	0.1034	0.1031	0.1029	0.1023	0.1025	0.1023
230			0.1046	0.1042	0.1039	0.1036	0.1034	0.1032	0.1031	0.1029
235			0.1051	0.1048	0.1045	0.1042	0.1039	0.1037	0.1036	0.1033
240				0.1053	0.1050	0.1048	0.1045	0.1043	0.1041	0.1039
245				0.1059	0.1056	0.1053	0.1050	0.1048	0.1046	0.1045
250					0.1062	0.1059	0.1056	0.1054	0.1052	0.1050

Initial Temperature F°	GAGE PRESSURE OF STEAM.									
	50	55	60	65	70	75	80	85	90	95
32	.0853	0.0852	0.0851	0.0850	0.0849	0.0848	0.0847	0.0846	0.0845	0.0845
35	.0853	0.0854	0.0853	0.0852	0.0851	0.0850	0.0849	0.0848	0.0848	0.0847
40	.0857	0.0857	0.0856	0.0855	0.0854	0.0854	0.0853	0.0852	0.0851	0.0850
45	.0862	0.0861	0.0860	0.0859	0.0858	0.0857	0.0856	0.0855	0.0855	0.0854
50	.0866	0.0865	0.0864	0.0863	0.0861	0.0861	0.0860	0.0859	0.0858	0.0858
55	.0870	0.0869	0.0868	0.0867	0.0866	0.0865	0.0863	0.0863	0.0862	0.0861
60	.0874	0.0872	0.0872	0.0870	0.0869	0.0868	0.0867	0.0867	0.0866	0.0865
65	.0877	0.0876	0.0875	0.0874	0.0873	0.0872	0.0871	0.0870	0.0870	0.0869
70	.0881	0.0880	0.0879	0.0878	0.0877	0.0876	0.0875	0.0874	0.0874	0.0873
75	.0885	0.0884	0.0883	0.0882	0.0881	0.0880	0.0879	0.0878	0.0877	0.0876
80	.0889	0.0888	0.0887	0.0886	0.0885	0.0884	0.0883	0.0882	0.0881	0.0880
85	.0893	0.0892	0.0891	0.0890	0.0889	0.0888	0.0887	0.0886	0.0885	0.0884
90	.0897	0.0896	0.0895	0.0894	0.0893	0.0891	0.0888	0.0890	0.0889	0.0888
95	.0901	0.0900	0.0899	0.0898	0.0897	0.0895	0.0894	0.0894	0.0893	0.0892
100	.0905	0.0904	0.0903	0.0902	0.0901	0.0900	0.0899	0.0898	0.0897	0.0896
105	.0909	0.0908	0.0907	0.0906	0.0905	0.0904	0.0903	0.0902	0.0901	0.0900
110	.0913	0.0912	0.0911	0.0910	0.0909	0.0908	0.0907	0.0906	0.0905	0.0904
115	.0917	0.0916	0.0915	0.0914	0.0913	0.0914	0.0911	0.0910	0.0909	0.0908
120	.0922	0.0921	0.0919	0.0918	0.0917	0.0918	0.0915	0.0914	0.0913	0.0912
125	.0926	0.0925	0.0924	0.0923	0.0921	0.0920	0.0919	0.0918	0.0918	0.0917
130	.0930	0.0929	0.0928	0.0927	0.0926	0.0925	0.0924	0.0923	0.0922	0.0921
135	.0935	0.0934	0.0932	0.0931	0.0930	0.0929	0.0928	0.0927	0.0926	0.0925
140	.0939	0.0938	0.0937	0.0935	0.0934	0.0933	0.0932	0.0931	0.0930	0.0929
145	.0944	0.0942	0.0941	0.0940	0.0939	0.0938	0.0937	0.0936	0.0935	0.0934
150	.0948	0.0947	0.0946	0.0944	0.0943	0.0942	0.0941	0.0940	0.0939	0.0939
155	.0953	0.0951	0.0950	0.0949	0.0948	0.0947	0.0946	0.0945	0.0944	0.0943
160	.0957	0.0956	0.0955	0.0954	0.0952	0.0951	0.0950	0.0949	0.0948	0.0947
165	.0962	0.0961	0.0959	0.0958	0.0957	0.0956	0.0955	0.0954	0.0953	0.0952
170	.0967	0.0965	0.0964	0.0963	0.0962	0.0960	0.0959	0.0958	0.0957	0.0956
175	.0972	0.0969	0.0969	0.0967	0.0966	0.0965	0.0964	0.0963	0.0962	0.0961
180	.0976	0.0971	0.0973	0.0972	0.0971	0.0970	0.0969	0.0968	0.0968	0.0966
185	.0981	0.0980	0.0978	0.0977	0.0976	0.0975	0.0974	0.0972	0.0971	0.0970
190	.0986	0.0984	0.0983	0.0982	0.0981	0.0979	0.0978	0.0977	0.0976	0.0975
195	.0991	0.0985	0.0988	0.0987	0.0986	0.0984	0.0983	0.0982	0.0981	0.0980
200	.0996	0.0994	0.0993	0.0992	0.0990	0.0989	0.0988	0.0988	0.0986	0.0985
205	.1001	0.0999	0.0998	0.0997	0.0995	0.0994	0.0993	0.0992	0.0991	0.0990
210	.1006	0.1004	0.1003	0.1001	0.1000	0.0999	0.0998	0.0997	0.0996	0.0995
212	.1008	0.1006	0.1005	0.1004	0.1003	0.1001	0.1000	0.0999	0.0998	0.0997
215	.1011	0.1009	0.1008	0.1006	0.1005	0.1004	0.1003	0.1001	0.1000	0.1000
220	.1016	0.1014	0.1013	0.1012	0.1010	0.1009	0.1008	0.1007	0.1006	0.1005
225	.1021	0.1020	0.1018	0.1017	0.1015	0.1014	0.1013	0.1012	0.1011	0.1010
230	.1026	0.1024	0.1024	0.1022	0.1022	0.1019	0.1018	0.1017	0.1016	0.1015
235	.1032	0.1030	0.1029	0.1027	0.1026	0.1025	0.1024	0.1022	0.1021	0.1018
240	.1037	0.1036	0.1034	0.1033	0.1031	0.1030	0.1029	0.1028	0.1026	0.1025
245	.1043	0.1041	0.1040	0.1038	0.1037	0.1036	0.1034	0.1033	0.1032	0.1031
250	.1048	0.1046	0.1045	0.1043	0.1043	0.1041	0.1040	0.1038	0.1037	0.1036

Initial Temperature F°	GAGE PRESSURE OF STEAM.									
	100	110	120	130	140	150	160	170	180	190
32	.0844	0.0842	0.0841	0.0840	0.0839	0.0838	0.0837	0.0836	0.0835	0.0834
35	.0846	0.0845	0.0843	0.0842	0.0841	0.0840	0.0840	0.0838	0.0837	0.0836
40	.0850	0.0848	0.0847	0.0846	0.0845	0.0843	0.0843	0.0841	0.0841	0.0840
45	.0853	0.0852	0.0851	0.0849	0.0848	0.0847	0.0846	0.0845	0.0844	0.0843
50	.0857	0.0855	0.0854	0.0853	0.0852	0.0851	0.0850	0.0849	0.0848	0.0847
55	.0861	0.0859	0.0858	0.0857	0.0855	0.0854	0.0853	0.0852	0.0851	0.0850
60	.0864	0.0863	0.0862	0.0860	0.0859	0.0858	0.0856	0.0856	0.0855	0.0854
65	.0868	0.0867	0.0865	0.0864	0.0863	0.0862	0.0861	0.0860	0.0859	0.0858
70	.0872	0.0870	0.0869	0.0868	0.0867	0.0865	0.0864	0.0863	0.0862	0.0861
75	.0876	0.0874	0.0873	0.0872	0.0870	0.0869	0.0868	0.0867	0.0866	0.0865
80	.0879	0.0878	0.0877	0.0875	0.0874	0.0873	0.0872	0.0871	0.0870	0.0869
85	.0883	0.0882	0.0880	0.0879	0.0878	0.0879	0.0876	0.0875	0.0874	0.0873
90	.0887	0.0886	0.0884	0.0883	0.0883	0.0881	0.0879	0.0878	0.0877	0.0876
95	.0891	0.0890	0.0888	0.0887	0.0886	0.0884	0.0883	0.0882	0.0881	0.0880
100	.0895	0.0894	0 0892	0.0891	0.0890	0.0888	0.0887	0.0886	0.0885	0.0884
105	.0899	0.0898	0.0896	0.0895	0.0894	0.0892	0.0891	0.0891	0.0889	0.0888
110	.0903	0.0902	0.0900	0.0897	0.0898	0.0896	0.0895	0.0894	0.0893	0.0892
115	.0907	0.0906	0.0904	0.0903	0.0902	0.0900	0.0899	0.0898	0.0897	0.0896
120	.0911	0.0910	0.0908	0.0907	0.0906	0.0904	0.0903	0.0902	0.0901	0.0900
125	.0916	0.0914	0.0913	0.0911	0.0908	0.0909	0.0907	0.0906	0.0905	0.0904
130	.0920	0.0918	0.0917	0.0915	0.0914	0.0913	0.0912	0.0910	0.0909	0.0908
135	.0924	0.0923	0.0921	0.0920	0.0918	0.0917	0.0916	0.0915	0.0914	0.0912
140	.0929	0.0927	0.0925	0.0924	0.0923	0.0921	0.0920	0.0919	0.0918	0.0917
145	.0933	0.0932	0.0930	0.0928	0.0927	0.0926	0.0924	0.0923	0.0922	0.0921
150	.0937	0.0936	0.0934	0.0933	0 0931	0.0930	0.0929	0.0927	0.0926	0.0925
155	.0942	0.0940	0.0939	0.0937	0.0936	0.0934	0.0933	0.0932	0.0931	0.0930
160	.0946	0.0945	0.0943	0.0942	0.0940	0.0939	0.0937	0.0936	0.0935	0.0934
165	.0951	0.0949	0.0948	0.0946	0.0945	0.0943	0.0942	0.0941	0.0939	0.0938
170	.0955	0.0954	0.0952	0.0951	0.0949	0.0948	0.0946	0.0945	0.0944	0.0943
175	.0960	0.0958	0.0957	0.0955	0.0954	0.0952	0.0951	0.0950	0.0948	0.0947
180	.0965	0.0963	0.0961	0.0960	0.0958	0.0957	0.0955	0.0954	0.0953	0.0952
185	.0969	0.0967	0.0966	0.0964	0.0963	0.0961	0.0960	0.0959	0.0958	0.0956
190	.0974	0.0972	0.0971	0.0969	0.0968	0.0966	0.0964	0.0963	0.0962	0.0961
195	.0979	0.0977	0.0976	0.0974	0.0972	0.0971	0.0970	0.0968	0.0967	0.0966
200	.0984	0.0982	0.0980	0.0979	0.0977	0.0976	0.0974	0.0973	0.0972	0.0971
205	.0989	0.0987	0.0985	0.0983	0.0982	0.0980	0.0979	0.0978	0.0976	0.0975
210	.0994	0.0992	0.0990	0.0988	0.0987	0.0985	0.0984	0.0983	0.0981	0.0980
212	.0996	0.0994	0.0992	0.0990	0.0989	0.0987	0.0986	0.0985	0.0983	0.0982
215	.0999	0.0996	0.0995	0.0993	0.0992	0.0990	0.0989	0.0987	0.0986	0.0985
220	.1004	0.1002	0.1000	0.0998	0.0997	0.0995	0.0994	0.0992	0.0991	0.0990
225	.1009	0.1006	0.1005	0.1003	0.1001	0.1000	0.0999	0.0997	0.0996	0.0995
230	.1012	0.1012	0.1010	0.1008	0.1007	0.1005	0.1003	0.1002	0.1001	0.1000
235	.1019	0.1017	0.1015	0.1013	0 1012	0.1010	0.1009	0.1007	0.1006	0.1005
240	.1024	0.1022	0.1020	0.1019	0.1017	0.1015	0.1014	0.1012	0.1011	0.1010
245	.1029	0 1027	0.1026	0.1024	0.1022	0.1020	0.1019	0.1018	0.1017	0.1015
250	.1035	0.1033	0.1031	0.1029	0.1027	0.1026	0.1025	0.1023	0.1022	0.1020

increase in temperature effected by an exhaust injector, operating with steam which would otherwise go to waste.

Q. 385 —What other source is available in the ordinary steam plant for heating the feed-water?
A.—The exhaust-steam.

Q. 386 —What two classes of heaters are used for this purpose?
A.—Open heaters and closed heaters.

Q. 387 —What is an open heater?
A.—A heater in which the exhaust-steam comes in direct contact and mixes with the water to be heated.

Q. 388 —What is a closed heater?
A.—A heater in which the exhaust steam is kept separate from the water to be heated, as by passing the one through tubes surrounded by the other.

Q. 389 —Can a heater be used to advantage on the exhaust of a condensing engine?
A.—Yes, a closed heater.

Q. 390 —How much heating surface is usually allowed per horse-power in a closed heater?
A.—About one-third of a square foot.

Q. 391 —What other important factors must be considered in proportioning heaters?
A.—Their volume must be sufficient to allow the water to flow through slowly and remain for a considerable time in contact with the heating-surface. An ordinary proportion is that they shall contain sufficient water to supply the engine for a quarter of an hour.

Q. 392 —How should the feed be managed to acquire the highest average temperature?
A.—The feed should be continuous and proportioned to the demand upon the boiler, i. e., the water-line should be kept at a constant level. If the level is allowed to fall, the feed must be supplied faster to catch up than if the required rate had been maintained, and has less time to be heated.

Q. 393 —What are the appliances generally used for feeding boilers?
A.—Steam and power-pumps and live steam and exhaust injectors.

Q. 394 —Which is the most economical?
A.—The exhaust steam injector where exhaust steam which

would otherwise go to waste is available. It not only feeds the boiler without the consumption of otherwise useful steam or power but heats the feed water as well.

Q. 395—Against how high a pressure can water be forced with an exhaust injector?
A.—About 75 pounds.

Q. 396—To what temperature does it heat the feed?
A.—About 190°.

Q. 397—Can the exhaust injector lift its water supply?
A.—No. The water must flow to it.

Q. 398—How warm feed will it handle?
A.—Not above 75°.

Q. 399—What is the principle by which an injector is able to force water against a pressure greater than that of the steam by which it is operated?
A.—The mingled jet of steam and water rushes into the vacuum formed by the condensation of the steam with such velocity that the momentum acquired carries it into the boiler against the greater pressure.

Q. 400—Into what classes may live steam injectors be divided?
A.—Lifting and non-lifting. Positive and automatic.

Q. 401—How high will a lifting injector raise its supply by suction?
A.—About 20 feet is the usual limit, although with cool water and low steam pressure water may be raised 25 feet.

Q. 402—How hot feed-water will an injector handle?
A.—With water flowing to the injector or under a light lift and a pressure of 60 pounds, water as hot as 150° may be handled. With greater lifts and higher steam pressure the temperature must be lower.

Q. 403—Against how high a pressure will an ordinary injector feed?
A.—With a low lift and cool water 150 to 160 pounds. Special injectors can be made to force against practically any pressure when operated by steam of a like pressure.

Q. 404—How hot does an injector deliver water?
A.—From 150° to 200°, according to steam pressure and proportion of its capacity at which injector is worked.

Q. 405—What is an automatic injector?
A.—One which will resume its work automatically when

working conditions are restored after having been stopped by an interruption of its water supply.

Q. 406.—How do steam-pumps, power-pumps and live steam injectors compare in efficiency as boiler feeders?

A.—The power-pump feeding through a heater is the most economical, the direct acting pump with heater next, the injector less economical than pump with heater but more so than pump feeding cold water. Table VI, by Prof. D. S. Jacobus, of Stevens Institute, gives the relative efficiency of steam and power pumps and injectors with and without heater, as used upon a boiler with 80 pounds gage pressure, the pump having a duty of 10,000,000 foot-pounds per hundred pounds of coal when no heater is used; the injector heating the water from 60° to 150° F. The first column gives the relative amount of coal required per unit of time, the amount for a direct-acting pump feeding water at 60° without a heater being taken as unity. The second column gives the percentage of saving in fuel by using the other methods instead.

TABLE VI.

Method of Supplying Feed Water to Boiler.	Relative amount of coal required.	Saving of fuel.
Direct acting pump feeding at 60° without heater	1.000	.0 per cent.
Injector feeding at 150°, without heater	.985	1.5 "
Injector feeding through heater heating from 160° to 200°	.938	6.2 "
Direct acting pump feeding through heater heating from 60° to 200°	.879	12.1 "
Geared pump, run from engine, feeding through heater heating from 60° to 200°	.868	13.2 "

Q. 407.—What are some of the principal causes for an injector's refusing to work?

A.—Leak in the suction-pipe; supply cut off by strainer getting clogged up; a loose lining inside of hose; a leak in the stem of the valve; too little steam pressure for the lift; dirt in the tubes, scale, iron cuttings or red lead blown in or drawn in through steam or supply-pipe; a bad check-valve, not lifting enough or not at all; valve in supply-pipe not properly regulated; a loose disk on the water supply valve on low steam;

wet steam, foaming boiler, new boilers full of grease, connecting to steam-pipe used for other purposes and used at same time; obstruction in the connection to the boiler.

Q. 408—How should the jets be cleaned when they have become scaled?

A.—By soaking in dilute muriatic acid, about one part of acid to ten parts of water.

Q. 409—What provision should be made for feeding a boiler?

A.—Both pump and injector should be supplied, avoiding a shut-down in case of accident to either, and in the case of a power-pump, insuring a hot feed when the engine is not running.

Q. 410—How are the capacities of boilers expressed?

A.—By horse-powers.

Q. 411—Upon what does the horse-power of a boiler depend?

A.—Upon its capacity to evaporate water.

Q. 412—At what rate must it evaporate water per horse-power?

A.—Thirty pounds per hour from a feed temperature at 100° F. into steam of 70 pounds gage pressure.

Q. 413—How may we readily compare the capacity of a boiler whose feed and pressure are different from the standard just given?

A.—By reducing both the standard and the performance of the given boiler to the equivalent evaporation from feed water of 212° F. into steam at atmospheric pressure, usually spoken of as the equivalent evaporation "from and at 212°" because the evaporation is "from" water at 212° into steam "at" 212°.

Q. 414—How may this be done?

A.—By subtracting the number of heat-units in a pound of water of the given feed temperature from the total number of heat-units in a pound of steam of the given pressure, dividing the difference by 965.7, and multiplying the number of pounds evaporated under the given conditions by the quotient. The product will be the number of pounds which would have been evaporated from and at 212°.

Q. 415—What is the equivalent evaporation from and at 212° of the standard evaporation just given? In other words if a boiler will evaporate 30 pounds of water from 100° into steam of 70 pounds in one hour, how many pounds will it

evaporate from feed of 212° into steam of atmospheric pressure in the same time?

A.—34.488; nearly 34 1-2.

[EXPLANATION: In a pound of steam of 70 pounds gage pressure there are, by Table IV, 1178.3 heat-units, and in a pound of water at 100°, there are 68.08 heat-units. It, therefore, took 1178.3 — 68.08 = 1110.22 heat-units to convert a pound of water into steam under those conditions. To convert a pound of water into steam at 212° into steam of atmospheric pressure requires 965.7 heat-units, and the 1110.22 units required under the conditions given would evaporate $\frac{1110.22}{965.7} = 1.1496$ pounds from and at 212°; and the heat required to evaporate 30 pounds from 100° to 70 pounds would therefore evaporate 30 × 1.1496 = 34.448 pounds from and at 212°.]

Q. 416—What is the "factor of evaporation?"

A.—The figure by which the evaporation at any given pressure and temperature must be multiplied in order to find the equivalent evaporation from and at 212°. For example, the factor of evaporation in the example just worked out is 1.1496.

Q. 417—Is it necessary to work out the factor of evaporation in every case?

A.—No. Tables are provided containing these factors for various temperatures and pressures. Table VII, taken from the Transactions of the A. S. M. E., is one of this kind, and its use saves a considerable amount of time.

Q. 418—What aid is provided to determine the horse-power of a boiler when the amount of evaporation is known, together with the pressure of the steam and the temperature of the feed?

A.—Table VIII gives the evaporation per hour per horse-power required at various temperatures and pressures. Divide the amount of water evaporated per hour by the boiler by the tabular figure for the given temperature and pressure. The quotient is the horse-power of the boiler.

Q. 419—A boiler carrying 90 pounds pressure, and having feed-water at 100°, evaporates 2987 pounds of water per hour, what is its horse-power?

A.—In Table VIII, under 90 lbs. pressure and opposite 100° is 29.87, the number of pounds required per hour per horse-power. The boiler therefore develops 2987 ÷ 29.87 = 100 horse-power.

FACTORS OF EVAPORATION.

Feed-water Temperature,	Gauge pressures..0+ Absolute pressures 15	10+ 25	20+ 35	30+ 45	40+ 55	45+ 60	50+ 65	52+ 67	54+ 69	56+ 71
	212° F	1.0003	1.0088	1.0149	1.0197	1.0237	1.0254	1.0271	1.0277	1.0283	1.0290
	209	35	1.0120	80	1.0228	68	86	1.0302	1.0309	1.0315	1.0321
	206	66	51	1.0212	60	99	1.0317	34	40	46	52
	203	98	83	43	91	1.0331	49	65	72	78	84
	200	1.0129	1.0214	75	1.0323	62	80	97	1.0403	1.0409	1.0415
	197	60	46	1.0306	54	94	1.0412	1.0428	34	41	47
	194	92	77	38	85	1.0425	43	60	66	72	78
	191	1.0223	1.0308	69	1.0417	57	74	91	97	1.0503	1.0510
	188	55	40	1.0400	48	88	1.0506	1.0522	1.0528	35	41
	185	86	71	32	80	1.0519	37	54	60	66	72
	182	1.0317	1.0403	63	1.0511	51	68	85	91	98	1.0604
	179	49	34	95	42	82	1.0600	1.0616	1.0623	1.0629	35
	176	80	65	1.0526	74	1.0613	31	48	54	60	66
	173	1.0411	97	57	1.0605	45	63	79	85	92	98
	170	43	1.0528	89	36	76	94	1.0710	1.0717	1.0723	1.0729
	167	74	59	1.0620	68	1.0707	1.0725	42	48	54	60
	164	1.0505	91	51	99	39	56	73	80	86	92
	161	37	1.0622	82	1.0730	70	88	1.0804	1.0811	1.0817	1.0823
	158	68	53	1.0714	62	1.0801	1.0819	36	42	48	54
	155	99	84	45	93	33	50	67	73	80	86
	152	1.0631	1.0716	76	1.0824	64	82	98	1.0905	1.0911	1.0917
	149	62	47	1.0808	55	95	1.0913	1.0930	36	42	48
	146	93	78	39	87	1.0926	44	61	67	73	79
	143	1.0724	1.0810	70	1.0918	58	75	92	98	1.1005	1.1011
	140	56	41	1.0901	49	89	1.1007	1.1023	1.1030	36	42
	137	87	72	33	80	1.1020	38	55	61	67	73
	134	1.0818	1.0903	64	1.1012	51	69	86	92	98	1.1104
	131	49	34	95	43	83	1.1100	1.1117	1.1123	1.1130	36
	128	81	66	1.1026	74	1.1114	32	48	55	61	67
	125	1.0912	97	57	1.1105	45	63	79	86	92	98
	122	43	1.1028	89	36	76	94	1.1211	1.1217	1.1223	1.1229
	119	74	59	1.1120	68	1.1207	1.1225	42	48	54	60
	116	1.1005	90	51	99	39	56	73	79	86	92
	113	36	1.1122	82	1.1230	70	88	1.1304	1.1310	1.1317	1.1323
	110	68	53	1.1213	61	1.1301	1.1319	35	42	48	54
	107	99	84	45	92	32	50	66	73	79	85
	104	1.1130	1.1215	76	1.1323	63	81	98	1.1404	1.1410	1.1416
	101	61	46	1.1307	55	94	1.1412	1.1429	35	41	47
	98	92	77	38	86	1.1426	43	60	66	73	79
	95	1.1223	1.1309	69	1.1417	57	75	91	97	1.1504	1.1510
	92	55	40	1.1400	48	88	1.1506	1.1522	1.1529	35	41
	89	86	71	31	79	1.1519	37	53	60	66	72
	86	1.1317	1.1402	63	1.1510	50	68	84	91	97	1.1603
	83	48	33	94	41	81	99	1.1616	1.1622	1.1628	34
	80	79	64	1.1525	73	1.1612	1.1630	47	53	59	65
	77	1.1410	95	56	1.1604	44	61	78	84	90	96
	74	41	1.1526	87	35	75	92	1.1709	1.1715	1.1722	1.1728
	71	72	58	1.1618	66	1.1706	1.1723	40	46	53	59
	68	1.1504	89	49	97	37	55	71	78	84	90
	65	35	1.1620	80	1.1728	68	86	1.1802	1.1809	1.1815	1.1821
	62	66	51	1.1711	59	99	1.1817	33	40	46	52
	59	97	82	43	90	1.1830	48	64	71	77	83
	56	1.1628	1.1713	74	1.1821	61	79	96	1.1902	1.1908	1.1914
	53	59	44	1.1805	52	92	1.1910	1.1927	33	39	45
	50	90	75	36	84	1.1923	41	58	64	70	76
	47	1.1721	1.1806	67	1.1915	54	72	89	95	1.2001	1.2007
	44	52	37	98	46	86	1.2003	1.2020	1.2026	32	39
	41	83	68	1.1929	77	1.2017	34	51	57	64	70
	38	1.1814	1.1900	60	1.2008	48	65	82	88	95	1.2101
	35	45	31	91	39	79	96	1.2113	1.2119	1.21	32
	32	76	62	1.2022	70	1.2110	1.2128	44	57		63

Feed-water Temperature.	Gauge pressures. 58+ / Absolute pressures 73	60+ 75	62+ 77	64+ 79	66+ 81	68+ 83	70+ 85	72+ 87	74+ 89	76+ 91
	212 °F	1.0295	1.0307	1.0307	1.0312	1.0318	1.0323	1.0329	1.0334	1.0339	1.0344
	209	1.0327	38	38	44	49	55	60	65	70	75
	206	58	64	70	75	81	86	91	97	1.0402	1.0407
	203	90	96	1.0401	1.0407	1.0412	1.0418	1.0423	1.0428	33	38
	200	1.0421	1.0427	33	38	44	49	54	59	65	69
	197	53	58	64	70	75	80	86	91	96	1.0501
	194	84	90	96	1.0501	1.0507	1.0512	1.0517	1.0522	1.0527	32
	191	1.0515	1.0521	1.0527	33	38	43	49	54	59	64
	188	47	53	58	64	69	75	80	85	90	95
	185	78	84	90	95	1.0601	1.0606	1.0611	1.0616	1.0622	1.0626
	182	1.0610	1.0615	1.0621	1.0627	32	37	43	48	53	58
	179	41	47	52	58	63	69	74	79	84	89
	176	72	78	84	89	95	1.0700	1.0705	1.0711	1.0716	1.0721
	173	1.0704	1.0709	1.0715	1.0721	1.0726	32	37	42	47	52
	170	35	41	46	52	57	63	68	73	78	83
	167	66	72	78	83	89	94	99	1.0805	1.0810	1.0815
	164	98	1.0803	1.0809	1.0815	1.0820	1.0825	1.0831	36	41	46
	161	1.0829	35	40	46	51	57	62	67	72	77
	158	60	66	72	77	83	88	93	98	1.0904	1.0908
	155	92	97	1.0903	1.0909	1.0914	1.0919	1.0925	1.0930	35	40
	152	1.0923	1.0929	34	40	45	51	56	61	66	71
	149	54	60	66	71	77	82	87	92	97	1.1002
	146	85	91	97	1.1002	1.1008	1.1013	1.1018	1.1024	1.1029	34
	143	1.1017	1.1022	1.1028	34	39	44	50	55	60	65
	140	48	54	59	65	70	76	81	86	91	96
	137	79	85	91	96	1.1102	1.1107	1.1112	1.1117	1.1122	1.1127
	134	1.1110	1.1116	1.1222	1.1127	33	38	43	49	54	59
	131	42	47	53	59	64	69	75	80	85	90
	128	73	79	84	90	95	1.1201	1.1206	1.1211	1.1216	1.1221
	125	1.1204	1.1210	1.1215	1.1221	1.1226	32	37	42	47	52
	122	35	41	47	52	58	63	68	73	78	83
	119	66	72	78	83	89	94	99	1.1305	1.1310	1.1315
	116	98	1.1303	1.1309	1.1315	1.1320	1.1325	1.1331	36	41	46
	113	1.1329	34	40	46	51	57	62	67	72	77
	110	60	66	71	77	82	88	93	98	1.1403	1.1408
	107	91	97	1.1403	1.1408	1.1414	1.1419	1.1424	1.1429	34	39
	104	1.1422	1.1428	34	39	45	50	55	60	65	70
	101	53	59	65	70	76	81	86	92	97	1.1502
	98	85	90	96	1.1502	1.1507	1.1512	1.1518	1.1523	1.1528	33
	95	1.1516	1.1521	1.1527	33	38	43	49	54	59	64
	92	47	53	58	64	69	75	80	85	90	95
	89	78	84	89	95	1.1600	1.1606	1.1611	1.1616	1.1621	1.1626
	86	1.1609	1.1615	1.1621	1.1626	32	37	42	47	52	57
	83	40	46	52	57	63	68	73	78	83	88
	80	71	77	83	88	94	99	1.1704	1.1710	1.1715	1.1720
	77	1.1702	1.1708	1.1714	1.1719	1.1725	1.1730	35	41	46	51
	74	34	39	45	51	56	61	67	72	77	82
	71	65	70	76	82	87	92	98	1.1803	1.1808	1.1813
	68	96	1.1802	1.1807	1.1813	1.1818	1.1824	1.1829	34	39	44
	65	1.1827	33	38	44	49	55	60	65	70	75
	62	58	64	69	75	80	86	91	96	1.1901	1.1906
	59	89	95	1.1901	1.1906	1.1912	1.1917	1.1922	1.1927	32	37
	56	1.1920	1.1926	32	37	43	48	53	58	63	68
	53	51	57	63	68	74	79	84	89	94	99
	50	82	88	94	99	1.2005	1.2010	12015	1.2021	1.2026	1.2031
	47	1.2013	1.2019	1.2025	1.2030	36	41	46	52	57	62
	44	44	50	56	61	67	72	78	83	88	93
	41	76	81	87	93	98	1.2103	1.2109	1.2114	1.2119	1.2124
	38	1.2107	1.2112	1.2118	1.2124	1.2129	34	40	45	50	55
	35	38	43	49	55	60	65	71	76	81	86
	32	69	75	80	86	91	97	1.2202	1.2207	1.2212	1.221?

Feed-water Temperature.	Gauge pressures lbs. .78+ Absolute pressures 93	80+ 95	82+ 97	84+ 99	86+ 101	88+ 103	90+ 105	92+ 107	94+ 109	96+ 111	98+ 113
212	1.0349	1.0353	1.0358	1.0363	1.0367	1.0372	1.0376	1.0381	1.0385	1.0389	1.0393
209	80	85	90	94	99	1.0403	1.0408	1.0412	1.0416	1.0421	1.0425
206	1.0411	1.0416	1.0421	1.0426	1.0430	35	39	43	48	52	56
203	43	48	52	57	62	66	71	75	79	83	88
200	74	79	84	89	93	98	1.0502	1.0506	1.0511	1 0515	1.0519
197	1.0506	1.0511	1.0515	1.0520	1.0525	1.0529	33	38	42	46	50
194	37	42	47	51	56	60	65	69	73	78	82
191	69	73	78	83	87	92	96	1.0601	1.0605	1.0609	1.0613
188	1.0600	1.0605	1.0610	1.0614	1.0619	1.0623	1.0628	32	36	40	45
185	31	36	41	46	50	55	59	63	68	72	76
182	63	68	72	77	81	86	90	95	99	1.0703	1.0707
179	94	99	1.0704	1.0708	1.0713	1.0717	1.0722	1.0726	1.0730	35	39
176	1.0725	1.0730	35	40	44	49	53	57	62	66	70
173	57	62	66	71	75	80	84	89	93	97	1.0801
170	88	93	98	1.0802	1.0807	1.0811	1.0816	1.0820	1.0824	1.0829	33
167	1.0819	1.0824	1.0829	34	38	43	47	51	56	60	64
164	51	56	60	65	69	74	78	83	87	91	95
161	82	87	92	96	1.0901	1.0905	1.0910	1.0914	1.0918	1.0923	1.0927
158	1.0913	1.0918	1.0923	1.0927	32	37	41	45	50	54	58
155	45	49	54	59	63	68	72	77	81	85	89
152	76	81	85	90	95	99	1.1004	1.1008	1.1012	1.1016	1.1021
149	1.1007	1.1012	1.1017	1.1021	1.1026	1.1030	35	39	43	48	52
146	38	43	48	53	57	62	66	70	75	79	83
143	70	74	79	84	88	93	97	1.1102	1.1106	1.1110	1.1114
140	1.1101	1.1106	1.1110	1.1115	1.1120	1.1124	1.1129	33	37	41	46
137	32	37	42	46	51	55	60	64	68	73	77
134	63	68	73	78	82	87	91	95	1.1200	1.1204	1.1208
131	95	99	1.1204	1.1209	1.1213	1.1218	1.1222	1.1227	31	35	39
128	1.1226	1.1231	35	40	45	49	53	58	62	66	71
125	57	62	67	71	76	80	85	89	93	98	1.1302
122	88	93	98	1.1302	1.1307	1.1311	1.1316	1.1320	1.1325	1.1329	33
119	1.1320	1.1324	1.1329	34	38	43	47	51	56	60	64
116	51	55	60	65	69	74	78	83	87	91	95
113	82	87	91	96	1.1401	1.1405	1.1409	1.1414	1.1418	1.1422	1.1426
110	1.1413	1.1418	1.1422	1.1427	32	36	41	45	49	53	58
107	44	49	54	58	63	67	72	76	80	85	89
104	75	80	85	89	94	99	1.1503	1.1507	1.1512	1.1516	1.1520
101	1.1506	1.1511	1.1516	1.1521	1.1525	1.1530	34	38	43	47	51
98	38	42	47	52	56	61	65	70	74	78	82
95	69	74	78	83	87	92	96	1.1601	1.1605	1.1609	1.1613
92	1.1600	1.1605	1 1609	1.1614	1.1619	1.1623	1.1628	32	36	40	45
89	31	36	41	45	50	54	59	63	67	72	76
86	62	67	72	76	81	85	90	94	98	1.1703	1.1707
83	93	98	1.1703	1.1707	1.1712	1.1717	1.1721	1.1725	1.1730	34	38
80	1.1724	1.1729	34	39	43	48	52	56	61	65	69
77	56	60	65	70	74	79	83	88	92	96	1.1800
74	87	91	96	1.1801	1.1805	1.1810	1.1814	1.1819	1.1823	1.1827	31
71	1.1818	1.1823	1.1827	32	36	41	45	50	54	58	62
68	49	54	58	63	68	72	77	81	85	89	94
65	80	85	89	94	99	1.1903	1.1908	1.1912	1.1916	1.1920	1.1925
62	1.1911	1.1916	1.1921	1.1925	1.1930	34	39	43	47	52	56
59	42	47	52	56	61	65	70	74	78	83	87
56	73	78	83	87	92	96	1.2001	1.2005	1.2010	1.2014	1.2018
53	1.2004	1.2009	1.2014	1.2018	1.2023	1.2028	32	36	41	45	49
50	35	40	45	50	54	59	63	67	72	76	80
47	66	71	76	81	85	90	94	98	1.2103	1.2107	1.2111
44	98	1.2102	1.2107	1.2112	1.2116	1.2121	1.2125	1.2130	34	38	42
41	1.2129	33	38	43	47	52	56	61	65	69	73
38	60	64	69	74	78	83	87	92	96	1.2200	1.2204
35	91	96	1.2200	1.2205	1.2209	1.2214	1.2218	1.2223	1.2227	31	35
32	1.2222	1.2227	31	36	41	45	49	54	58	62	67

Feed-water Temperature.	Gauge Pressures lbs. 100+ / Absolute Pressures 115	105+ / 120	110+ / 125	115+ / 130	120+ / 135	125+ / 140	130+ / 145	135+ / 150	140+ / 155	145+ / 160	150+ / 165
212	1.0397	1.0407	1.0417	1.0427	1.0436	1.0445	1.0453	1.0462	1.0470	1.0478	1.0486
209	1.0429	39	49	58	67	76	85	93	1.0501	1.0509	1.0517
206	60	70	80	89	99	1.0508	1.0516	1.0525	33	41	48
203	92	1.0502	1.0511	1.0521	1.0530	39	48	56	64	72	80
200	1.0523	33	43	52	62	70	79	87	96	1.0604	1.0611
197	55	65	74	84	93	1.0602	1.0610	1.0619	1.0627	35	43
194	86	96	1.0606	1.0615	1.0624	33	42	50	58	66	74
191	1.0617	1.0627	37	47	56	65	73	82	90	98	1.0706
188	49	59	69	78	87	96	1.0705	1.0713	1.0721	1.0729	37
185	80	90	1.0700	1.0709	1.0719	1.0727	36	44	53	61	68
182	1.0712	1.0722	31	41	50	59	67	76	84	92	1.0800
179	43	53	63	72	81	90	99	1.0807	1.0815	1.0823	31
176	74	84	94	1.0803	1.0813	1.0821	1.0830	39	47	55	62
173	1.0806	1.0816	1.0825	35	44	53	61	70	78	86	94
170	37	47	57	66	75	84	93	1.0901	1.0909	1.0917	1.0925
167	68	78	88	97	1.0907	1.0915	1.0924	32	41	49	56
164	1.0900	1.0910	1.0919	1.0929	38	47	55	64	72	80	88
161	31	41	51	60	69	78	87	95	1.1003	1.1011	1.1019
158	62	72	82	91	1.1000	1.1009	1.1018	1.1026	35	43	50
155	93	1.1003	1.1013	1.1023	32	41	49	58	66	74	82
152	1.1025	35	44	54	63	72	81	89	97	1.1105	1.1113
149	56	66	76	85	94	1.1103	1.1112	1.1120	1.1128	36	44
146	87	97	1.1107	1.1116	1.1126	34	43	51	60	68	75
143	1.1118	1.1129	38	48	57	66	74	83	91	99	1.1207
140	50	60	70	79	88	97	1.1206	1.1214	1.1222	1.1230	38
137	81	91	1.1201	1.1210	1.1219	1.1228	37	45	53	61	69
134	1.1212	1.1222	32	41	51	59	68	76	85	93	1.1300
131	43	53	63	73	82	91	99	1.1308	1.1316	1.1324	32
128	75	85	94	1.1304	1.1313	1.1322	1.1331	39	47	55	63
125	1.1306	1.1316	1.1326	35	44	53	62	70	78	86	94
122	37	47	57	66	75	84	93	1.1401	1.1409	1.1417	1.1425
119	68	78	88	97	1.1407	1.1415	1.1424	32	41	49	56
116	99	1.1409	1.1419	1.1429	38	47	55	64	72	80	88
113	1.1431	41	50	60	69	78	86	95	1.1503	1.1511	1.1519
110	62	72	82	91	1.1500	1.1509	1.1518	1.1526	34	42	50
107	93	1.1503	1.1513	1.1522	31	40	49	57	65	73	81
104	1.1524	34	44	53	62	71	80	88	97	1.1605	1.1612
101	55	65	75	84	94	1.1602	1.1611	1.1620	1 1628	36	43
98	86	96	1.1606	1.1616	1.1625	34	42	51	59	67	75
95	1.1618	1.1628	37	47	56	65	73	82	90	98	1.1706
92	49	59	68	78	87	96	1.1705	1.1713	1.1721	1.1729	37
89	80	90	1.1700	1.1709	1.1718	1.1727	36	44	52	60	68
86	1.1711	1.1721	31	40	49	58	67	75	83	91	99
83	42	52	62	71	80	89	98	1.1806	1.1815	1.1823	1.1830
80	73	83	93	1.1802	1.1812	1.1820	1.1829	37	46	54	61
77	1.1804	1.1814	1.1824	34	43	52	60	69	77	85	93
74	35	45	55	65	74	83	91	1.1900	1.1908	1.1916	1.1924
71	67	77	86	96	1.1905	1.1914	1.1922	31	39	47	55
68	98	1.1908	1.1917	1.1927	36	45	54	62	70	78	86
65	1.1929	39	49	58	67	76	85	93	1.2001	1.2009	1.2017
62	60	70	80	89	98	1.2007	1.2016	1.2024	32	40	48
59	91	1.2001	1.2011	1.2020	1.2029	38	47	55	63	71	79
56	1.2022	32	42	51	60	69	78	86	94	1.2102	1.2110
53	53	63	73	82	91	1.2100	1.2109	1.2117	1.2126	34	41
50	84	94	1.2104	1.2113	1.2123	31	40	48	57	65	72
47	1.2115	1.2125	35	44	54	63	71	80	88	96	1.2203
44	46	56	66	76	85	94	1.2202	1.2211	1.2219	1.2227	35
41	77	87	97	1.2207	1.2216	1.2225	33	42	50	58	66
38	1.2208	1.2219	1.2228	38	47	56	64	73	81	89	97
35	40	50	59	69	78	87	95	1.2304	1.2312	1.2320	1.2328
32	71	81	90	1.2300	1.2309	1.2318	1.2326	35	43	51	59

REQUIRED HOURLY EVAPORATION PER COMMERCIAL HORSE-POWER

AT VARIOUS TEMPERATURES OF FEED AND PRESSURES OF STEAM.

°F.	STEAM PRESSURE IN POUNDS BY GAUGE.																					°F.
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
50	29.51	29.29	29.14	29.02	28.92	28.84	28.77	28.70	28.64	28.59	28.54	28.49	28.45	28.41	28.37	28.33	28.29	28.26	28.23	28.20	28.17	50
60	29.77	29.55	29.40	29.28	29.18	29.09	29.02	28.95	28.89	28.84	28.79	28.74	28.69	28.65	28.61	28.57	28.54	28.51	28.48	28.45	28.42	60
70	30.04	29.81	29.66	29.54	29.44	29.35	29.27	29.21	29.15	29.09	29.04	28.99	28.94	28.90	28.86	28.82	28.78	28.75	28.72	28.69	28.66	70
80	30.31	30.08	29.93	29.80	29.70	29.61	29.53	29.46	29.40	29.34	29.29	29.24	29.19	29.15	29.11	29.07	29.03	29.00	28.97	28.94	28.91	80
90	30.59	30.36	30.20	30.07	29.97	29.88	29.80	29.73	29.67	29.61	29.55	29.50	29.45	29.41	29.37	29.33	29.29	29.25	29.22	29.19	29.16	90
100	30.88	30.64	30.47	30.34	30.24	30.15	30.07	30.00	29.93	29.87	29.82	29.77	29.72	29.67	29.63	29.59	29.55	29.51	29.48	29.45	29.42	100
110	31.17	30.93	30.76	30.63	30.52	30.43	30.34	30.27	30.20	30.14	30.09	30.04	29.99	29.94	29.90	29.86	29.82	29.78	29.74	29.71	29.68	110
120	31.46	31.22	31.05	30.91	30.80	30.71	30.63	30.55	30.48	30.42	30.36	30.31	30.26	30.21	30.17	30.13	30.09	30.05	30.01	29.98	29.95	120
130	31.76	31.52	31.34	31.20	31.09	30.99	30.91	30.83	30.76	30.70	30.65	30.59	30.54	30.49	30.45	30.41	30.37	30.33	30.29	30.25	30.22	130
140	32.07	31.82	31.64	31.50	31.38	31.29	31.20	31.12	31.05	30.99	30.93	30.88	30.83	30.78	30.73	30.69	30.65	30.61	30.57	30.53	30.50	140
150	32.39	32.12	31.94	31.80	31.68	31.58	31.50	31.42	31.35	31.28	31.22	31.17	31.12	31.07	31.02	30.97	30.93	30.89	30.85	30.81	30.78	150
160	32.71	32.44	32.26	32.11	31.99	31.89	31.80	31.72	31.65	31.58	31.52	31.46	31.41	31.36	31.31	31.27	31.23	31.19	31.15	31.11	31.08	160
170	33.03	32.76	32.58	32.43	32.31	32.20	32.11	32.03	31.96	31.89	31.83	31.77	31.71	31.66	31.61	31.56	31.52	31.48	31.44	31.40	31.37	170
180	33.37	33.09	32.90	32.75	32.63	32.52	32.43	32.34	32.27	32.20	32.14	32.08	32.02	31.97	31.92	31.87	31.83	31.79	31.75	31.71	31.67	180
190	33.71	33.43	33.23	33.08	32.95	32.84	32.75	32.66	32.59	32.52	32.45	32.39	32.33	32.28	32.23	32.18	32.14	32.10	32.06	32.02	31.98	190
200	34.06	33.77	33.57	33.41	33.28	33.17	33.08	32.99	32.91	32.84	32.77	32.71	32.65	32.60	32.55	32.50	32.45	32.41	32.37	32.33	32.29	200
212	34.40	34.18	33.98	33.80	33.69	33.58	33.48	33.39	33.31	33.24	33.17	33.11	33.05	32.99	32.94	32.89	32.84	32.80	32.76	32.72	32.68	212

A committee of the American Society of Mechanical Engineers on a "Standard Method of Boiler Trials," recommended the adoption of 30 pounds of water from feed of 100° F. into steam at 70 pounds gauge pressure as the rate of evaporation to be required of a boiler per commercial horse-power, and this standard is now generally used. This is at the rate of 33,305 B.T.U. per hourly horse-power. The above table gives the number of pounds required to be evaporated per hour per horse-power at other temperatures and pressures. Formula: $33{,}305 \div (H - h) = N$.

Q. 420—What relation is there between the two tables, VII and VIII?

A.—If the evaporation per horse-power from Table VIII, be multiplied by the factor of evaporation, from table VII, the result will be 34.488. That is, Table VIII can be made up by dividing 34.488, which is the evaporation per horse-power per hour from and at 212°, by the factors of evaporation for other pressures and temperatures.

SECTION VII.

Boiler Heating Surface.

Q. 421—How can the horse-power of a boiler be figured roughly?

A.—From the heating-surface.

Q. 422—How many square feet of heating-surface are allowed per horse-power in horizontal return tubular boilers with moderate rates of combustion?

A.—About 12.

Q. 423—In water tube boilers?

A.—10 to 12.

Q. 424—Why should there be any difference?

A.—Because in one type of boiler the heating-surface is more effective than in another.

Q. 425—How many square feet of heating surface are allowed per horse-power in plain cylinder boilers?

A.—6 to 10.

Q. 426—In flue boilers?

A.—8 to 12.

Q. 427—In locomotive boilers used with natural draft?

A.—12 to 16.

Q. 428—In vertical tubular boilers?

A.—12 to 15.

Q. 429—What is heating-surface?

A.—Any surface exposed to heat on one side and water on the other.

Q. 430—What is superheating surface?

A.—Any surface exposed to heat on one side and steam on the other.

Q. 431—When the dividing surface is curved, as in the case of tubes, there is a considerable difference between the inside and outside surfaces. Which is used?

A.—The smaller or inside surface.

Q. 432—Why?

A.—Let Fig. 52 represent a cylindrical shell surrounded by fire. It is very evident that the heat taken up by the water must be imparted to it by the inner surface. Let Fig. 53 represent a reversal of these conditions. The heat received by the water is imparted to it by the outer surface, which, in turn, receives the supply from the inner surface. In either case the limiting value of the heat transmitted is determined by the transmitting power of the inner surface.

Q. 433—What parts of a plain cylindrical boiler are useful as heating surface?

A.—The lower half of the shell and the area of the head below the water line. This last may be taken as one-half the area of the head. There is only one head exposed to flame in this type of boiler.

FIG. 52

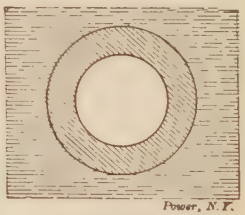


FIG. 53

Q. 434—How would you determine the heating surface of single-flue boilers? (Fig. 6.)

A.—(One-half of the area of the shell) plus (the area of the flue) plus (the area of one head minus twice the cross-section of the flue). This last figure is arrived at by considering that one-half of each head is below the water line, and that from each half-head is to be deducted the cross section of the flue, giving two times the half-head minus twice the cross-section of flue. This is equivalent to the last term of the rule above. Expressed in the shape of a formula this rule is:

$$H\ S = \tfrac{1}{2}\ S + F + H - 2\ C$$

where H S = heating surface;
S = area of shell;
F = inside surface of flue;
H = area of head;
C_F^F = cross-section of flue.

Q. 435—What is the heating-surface of a two-flue boiler?

A.—(One-half the area of shell) plus (twice the area of one flue) plus (the area of one head minus four times the cross-section of one flue). This is simply modifying the rule for single-flue boilers by allowing for the extra flue. Expressed in a formula, this is:

$$H\ S = \tfrac{1}{2}\ S + 2F + H - 4C_F$$

Q. 436—How do you find the heating-surface of multiflue boilers?

A.—The rule is similar to the last, modified to take in the extra flues, or:

$$H\ S = \tfrac{1}{2}\ S + N \times F + H - (2\ N \times C_F)$$

where N = number of flues.

Q. 437—How do you find the heating-surface of cylindrical fire-tube or horizontal return tubular boilers?

A.—(Half the area of shell) plus (area of tubes) plus (area of one head minus twice the total cross-section of the tubes.) This is the same as for multiflue boilers, or in the shape of a formula this is:

$$H\ S = \tfrac{1}{2}\ S + N \times T + H - 2N \times C_T$$

where N = number of tubes;
T = inside surface of one tube;
C_T = cross-sectional area of one tube.

Q. 438—What is the heating-surface of fire-box boilers?

A.—These are formed by the additional of a firebox surrounded by water-legs to the cylindrical tubular boiler. The rule is: (Area of crown sheet) plus (area of firebox back-head above grate minus the area of furnace-door opening) plus (area of fire-box tube sheet above grate minus total cross section of tubes) plus (twice the area of fire-box side-sheet above the grate) plus (area of front tube-sheet below water-line minus total cross-section of tubes) plus (area of tubes.) Expressed as formula, this rule gives:

$$H\ S = K + B - D + H - 2N \times C_T + 2F + H^1 + N \times T$$

where K = area of crown-sheet;
B = " " fire-box back-head;
D = " " furnace-door;
H = area of fire-box tube-sheet above the grates;
C_T = cross-sectional area of one tube:
F = area of one fire-box side-sheet above the grate;
H^1 = area of front tube-sheet below water-line;
T = inside surface of one tube.

Q. 439—Name the heating-surface of Scotch boilers.

A.—In this type the grates are set in the main flues, thus giving only one-half of each flue area as heating surface. But there are two main flues, so that the total heating surface due to them is equal to the area of one flue. This gives the following rule: (area of main flue) plus (area of one head between the grate and water line) minus (the total cross-section of tubes, plus the cross-section of one flue) plus (the area of the tubes). Expressed in the shape of a formula, this is:

$$H S = F + H - N \times C_T - C_F + N \times T$$

where H = area of one head between the grate and the water line.

Q. 440—How is the area in the half-shell determined?

A.—By multiplying the diameter by 3.1416, dividing by 2,

TABLE IX. — Boiler Tubes.

External Diameter.	Standard Thickness.	Inside Diameter.	Inside Circumference.	Outside Circumference.	Heating Surface Per Foot of Length.	Length Per Sq. Foot of Heating Surface.	Cross Section in Square Feet.	
							Outside Diameter.	Inside Diameter.
1	.072	.856	2 6892	3.1416	.2241	4.46	.0055	.003996
1¼	.072	1.106	3.4746	3.9270	.2896	3.45	.0085	.006560
1½	.083	1.334	4.1908	4 7124	.3492	2.86	.0123	.009637
1¾	.095	1.560	4.9008	5.4988	.4084	2.45	.0167	.013290
2	.095	1.810	5.6858	6.2832	.4739	2.11	.0218	.017870
2¼	.095	2.060	6.4717	6.7066	.5393	1.86	.0276	.023112
2⅜	.109	2.282	7.1691	7.8540	.5974	1.67	.0341	.028402
2¾	.109	2.532	7.9545	8.6394	.6629	1.51	.04120	.034870
3	.109	2.782	8.7399	9.4248	.7283	1.37	.04909	.041451
3¼	.120	3 010	9.4562	10.2102	.7880	1.27	.05761	.049412
3½	.120	3.260	10.2416	10.9950	.8535	1.17	.06681	.05796
3¾	.120	3.510	11.0270	11.7810	.9189	1.08	.0767	.067195
4	.134	3.732	11 7244	12.5660	.9770	1.02	.0872	.075270
4½	.134	4.232	13.2952	14.132	1.1079	.903	.1104	.092680
5	.148	4.704	14.7780	15.708	1.2315	.812	.1364	.126940
6	.165	5.670	17.8128	18.850	1.4844	.674	.1963	.175340
7	.165	6.670	20 9544	21.991	1.7462	.573	.2673	.24268
8	.165	7.670	24.0960	25.133	2 0080	.498	.3491	.319738
9	.180	8.640	27.1434	28.274	2.2619	.442	.4418	.400207
10	.203	9.594	30.1405	31.416	2.5117	.398	.5454	.500204
11	.220	10.560	33.1753	34.558	2.7646	.364	.6600	.607214
12	.229	11.542	36.2603	37.699	3.0217	.331	.7854	.726548
13	.238	12.524	39.3454	40.841	3.2788	.305	.9217	.854794
14	.248	13.504	42.4242	43.982	3.5354	.282	1.0690	.994611
15	.259	14.482	45.4967	47.124	3 7914	.264	1.2202	1.143824
16	.270	15.460	48.5691	50.265	4.0474	.247	1.3959	1.303609
18	.300	17.400	54.6638	56.549	4.5553	.219	1.7672	1.651235
20	.312	19.376	60.8716	62.832	5.0726	.197	2.1814	2.0387
22	.344	21.312	66.9534	76.026	5 5794	.179	2.6398	2.4773
24	.375	23.250	73.0422	90.478	6.0869	.164	3.1416	2.9467

and then multiplying by the length of the boiler. For example, take a boiler 5 feet in diameter and 15 feet long. The circumference of the boiler would be $5 \times 3.1416 = 15.708$ feet, one-half of which is 7.854 feet. The length is 15 feet; so that if the lower half of the boiler were straightened out as shown in Fig. 54, the sheet of which we are trying to get the area would be a rectangle 15 feet long and 7.854 feet wide, containing therefore $7.854 \times 15 = 117.81$ square feet.

Q. 441 —What is meant when a "3 inch boiler tube" is spoken of?

A.—A tube three inches in external diameter. That is, boiler tubes are rated by their external diameter. Table IX gives the standard sizes of lapwelded charcoal-iron boiler tubes.

Q. 442 —How would you find the heating-surface of 66 tubes, 15 feet long, 3 inches in diameter?

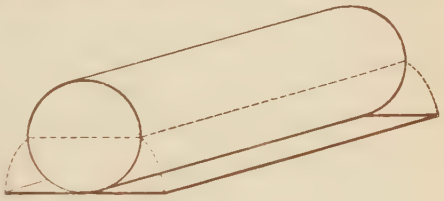


FIG. 54.

A.—The standard thickness of 3-inch tube is .109 of an inch (see Table IX). The inside diameter is therefore $3 - (2 \times .109) = 2.78$. The circumference due to this diameter is $2.78 \times 3.1416 = 8.73$ inches. Each tube is 15 feet (= 180 inches) long, and contains

$$\frac{180 \times 8.73}{144} = 10.91 \text{ sq. ft.}$$

The division by 144 is to reduce the square inches to square feet. As there are sixty-six tubes there would be in the lot

$$66 \times 10.91 = 720.06 \text{ sq. ft.}$$

Q. 443 —How do you determine the cross-sectional area of 66 tubes 3 inches in diameter?

A.—This is simply the area of 66 circles 3 inches in diameter. The area of one such is $3 \times 3 \times .7854 = 7.0686$ square inches. But it is necessary to reduce this to square feet in order to have all quantities the same. This gives $7.0686 \div 144 = .04909$ square feet. 66 tubes would therefore have $66 \times .04909 = 3.23994$ square feet of sectional area.

Q. 444 —What aids can be employed in the calculation of heating-surface?

A.—Table X gives the heating-surface of the half

TABLE X

HEATING SURFACE IN HALF SHELL OF CYLINDRICAL BOILERS.

Length in Feet.	DIAMETER OF SHELL, IN INCHES.									
	24	26	28	30	32	34	36	38	40	42
7	21.99	23.82	25.66	27.49	29.33	31.15	32.97	34.79	36.65	38.48
7.5	23.56	25.52	27.50	29.46	31.43	33.38	33.33	37.28	39.27	41.23
8	25.13	27.22	29.32	31.42	33.52	35.60	37.68	39.76	41.89	43.98
8.5	26.70	28.93	31.15	33.38	35.62	37.83	40.04	42.25	44.51	46.73
9	28.28	30.63	32.99	35.34	37.71	40.05	42.39	44.73	47.12	49.48
9.5	29.85	32.33	34.82	37.31	39.81	42.28	44.75	47.22	49.74	52.23
10	31.42	34.03	36.65	39.27	41.80	44.50	47.10	49.70	52.36	54.97
10.5	32.99	35.73	38.48	41.24	43.90	46.73	49.47	52.19	54.98	57.72
11	34.56	37.44	40.32	43.20	45.99	48.95	51.81	54.67	57.59	60.47
11.5	36.13	39.14	42.15	45.17	48.09	51.18	54.17	57.16	60.21	63.22
12	37.70	40.84	43.98	47.13	50.28	53.40	56.52	59.64	62.83	65.97
12.5	39.27	42.54	45.82	49.09	52.38	55.63	58.88	62.13	65.45	68.72
13	40.84	44.24	47.65	51.05	54.47	57.85	61.23	64.61	68.07	71.47
13.5	42.41	45.94	49.48	53.02	56.57	60.08	63.59	67.10	70.69	74.22
14	43.99	47.65	51.31	54.98	58.66	62.30	65.94	69.58	73.30	76.96
14.5	45.56	49.35	53.15	56.94	60.76	64.53	68.30	72.07	75.92	79.71
15	47.13	51.05	54.98	58.90	62.85	66.75	70.65	74.55	78.54	82.46
15.5	48.70	52.75	56.81	60.87	64.95	68.98	73.01	77.04	81.16	85.21
16	50.27	54.45	58.64	62.82	67.04	71.20	75.36	79.52	83.77	87.96
16.5	51.84	56.16	60.48	64.79	69.15	73.43	77.72	82.01	86.39	90.71
17	53.41	57.86	62.31	66.75	71.23	75.65	80.87	84.49	89.01	93.47
17.5	54.98	59.56	64.14	68.72	73.33	77.88	83.23	86.98	91.63	96.22
18	56.55	61.26	65.97	70.69	75.42	80.10	84.78	89.46	94.25	98.95
18.5	58.11	62.96	67.81	72.65	77.52	82.33	87.14	91.95	96.87	101.70
19	59.78	64.67	69.64	74.61	79.61	84.55	89.49	94.43	99.49	104.45
19.5	61.27	66.37	71.47	76.58	81.71	86.78	91.85	96.92	102.11	107.20
20	62.83	68.07	73.39	78.54	83.80	89.00	94.20	99.40	102.72	109.94
21	65.98	71.46	76.96	82.48	87.80	93.46	98.94	104.38	109.96	115.44
22	69.12	74.88	80.64	86.40	91.98	97.90	103.62	109.34	115.18	120.94
23	72.26	78.28	84. 0	90.34	96.18	102.36	108.34	114.32	120.42	126.44
24	75.40	81.68	87.96	94.26	100.56	106.80	113.04	119.28	123.04	131.94
25	78.54	85.08	91.64	98.18	104.76	111.26	117.76	124.26	130.90	137.44
26	81.68	88.48	95.30	102.10	108.94	115.70	122.46	129.22	136.14	142.94
27	84.82	91.88	98.96	106.04	113.14	120.16	127.18	134.20	141.38	144.44
28	87.96	94.28	102.64	109.96	117.32	124.60	131.88	139.16	146.60	153.92
29	91.12	98.70	106.30	113.88	121.52	129.06	136.60	144.14	151.84	159.42
30	94.26	102.10	109.96	117.80	125.70	133.50	141.30	149.10	157.08	164.92
31	97.40	105.50	113.62	121.74	129.80	137.96	146.02	154.08	162.32	170.42
32	100.52	108.88	117.28	125.68	134.08	141.32	160.16	169.00	178.04	175.92
33	103.68	112.32	120.96	129.59	138.30	146.86	154.44	164.02	172.78	181.42
34	106.82	115.72	124.62	133.50	142.46	151.30	161.74	168.98	178.02	186.94
35	109.96	119.12	128.28	137.42	146.66	155.76	166.46	173.96	183.26	192.44
36	113.10	122.52	131.94	141.38	150.84	160.20	169.58	178.92	188.50	197.90
37	116.24	125.92	135.62	145.30	155.04	164.66	174.28	183.90	193.74	203.40
38	119.40	129.34	139.28	149.22	159.26	169.10	178.98	188.86	199.98	208.90
39	122.54	133.74	142.94	153.16	162.42	173.56	183.70	193.84	205.42	214.40
40	125.76	136.14	146.60	157.08	167.60	178.00	188.40	198.80	209.44	219.88
Area of head, square feet.	3.42	3.69	4.21	4.91	5.59	6.30	7.07	7.88	8.73	9.62

Length in Feet.	DIAMETER OF SHELL, IN INCHES.									
	44	46	48	50	52	54	56	58	60	62
7	40.32	42.15	43.98	45.82	47.65	49.48	51.31	53.15	54.98	56.81
7.5	43.20	45.16	46.12	49.09	51.05	53.01	54.98	56.94	58.90	60.87
8	46.08	48.17	50.26	52.36	54.45	56.54	58.64	60.74	62.83	64.93
8.5	48.96	51.18	53.40	55.63	57.86	60.07	62.31	64.53	66.75	68.98
9	51.84	54.19	56.55	58.91	61.26	63.61	65.97	68.33	70.69	73.04
9.5	54.72	57.20	59.69	62.18	64.66	67.14	69.64	72.13	74.61	77.10
10	57.60	60.21	62.83	65.45	68.07	70.68	73.30	75.92	78.54	81.16
10.5	60.48	63.22	65.97	68.73	71.47	74.21	76.97	79.72	82.46	85.22
11	63.36	66.23	69.11	72.00	74.87	77.75	80.63	83.51	86.39	89.27
11.5	66.24	69.24	72.25	75.27	78.28	81.28	84.30	87.31	90.31	93.33
12	69.12	72.25	75.40	78.55	81.68	84.82	87.96	91.11	94.25	97.39
12.5	72.00	75.26	78.55	81.82	85.09	88.35	91.63	94.90	98.17	101.45
13	74.87	78.27	81.68	85.09	88.49	91.88	95.29	98.70	102.10	105.51
13.5	77.75	81.28	84.82	88.36	91.89	95.41	98.96	102.49	106.02	109.56
14	80.63	84.29	87.96	91.64	95.30	98.95	102.63	106.29	109.96	113.62
14.5	83.51	87.30	91.10	94.91	98.70	102.48	106.29	110.09	113.88	117.68
15	86.39	90.31	94.24	98.18	102.10	106.02	109.96	113.88	117.81	121.74
15.5	89.27	93.32	97.38	101.46	105.51	109.55	113.62	117.68	121.73	125.80
16	92.15	96.33	100.53	104.73	108.91	113.09	117.29	121.47	125.66	129.85
16.5	95.03	99.34	103.67	108.00	112.31	114.62	120.95	125.27	129.58	133.91
17	97.91	102.35	106.81	111.28	115.72	120.16	124.62	129.07	133.52	137.97
18	103.67	108.37	113.09	117.82	122.52	127.22	131.95	136.66	141.37	146.09
19	109.43	114.39	119.37	124.37	129.33	134.29	139.28	144.25	149.23	154.20
20	115.19	120.42	125.66	130.90	136.14	141.36	146.61	151.84	157.08	162.32
Area of head, square feet.	10.56	11.54	12.57	13.64	14.75	15.90	17.10	18.35	19.63	20.97

Length in Feet.	DIAMETER OF SHELL, IN INCHES.									
	64	66	68	70	72	74	76	78	80	84
7	58.64	60.47	62.31	64.14	65.97	67.81	69.64	71.47		
7.5	62.83	64.79	66.76	68.72	70.69	72.65	74.61	76.58		
8	67.02	69.11	71.21	73.30	75.40	77.49	79.59	81.68		
8.5	71.21	73.43	75.66	77.89	80.12	82.34	84.56	86.79		
9	75.40	77.75	80.11	82.47	84.82	87.18	89.54	91.89		
9.5	79.58	82.07	84.56	87.05	89.54	92.02	94.51	97.00		
10	83.78	86.30	89.01	91.63	94.24	96.87	99.48	102.10	102.10	107.34
10.5	87.96	86.71	93.47	96.21	98.96	101.71	104.46	107.21	107.21	112.71
11	92.15	95.03	97.92	100.79	103.68	106.55	109.43	112.31	112.31	118.08
11.5	96.34	99 35	102.37	105.37	108.40	111.40	114.41	117.42	117.42	123.45
12	100.53	103.67	106.82	109.96	113.09	116.24	119.38	122.52	122.52	128.81
12.5	104.72	107.99	111.27	114.54	117.81	121.08	124.36	127.63	127.63	134.18
13	108.91	112.31	115.72	119.12	122.52	125.93	129.33	132.73	132.73	139.55
13.5	113.10	116.63	120.17	123.70	130.24	130.77	134.30	137.84	137.84	144.92
14	117.28	120.95	124.62	128.28	131.94	135.61	139.28	142.94	142.94	150.27
14.5	121.48	125.27	129.07	132.86	136.66	140.46	144.25	148.05	148.05	155.64
15	125.66	129.58	133.52	137.44	141.37	145.30	149.23	153.15	153.15	161.00
15.5	129.85	133.90	137.98	142.03	146.09	150.14	154.20	158.26	158.26	166.37
16	134.04	138.22	142.43	146.61	150.79	154.99	159.17	163.36	163.36	171.74
16.5	138.23	142.54	146.88	151.19	155.51	159.83	164.15	168.47	168.47	177.11
17	142.42	146.86	151.32	155.77	160.21	164.67	169.12	173.57		
18	150.80	155.50	160.22	164.93	169.64	174.36	179.07	183.78		
19	159.17	164.14	169.12	174.10	179.06	184.05	189.02	193.99		
20	167.55	172.78	178.02	183.26	188.48	193.73	198.97	204.20		
Area of head, square feet.	22.34	23.76	25.22	26.73	28.27	29.87	31.50	33.18	34.91	38.49

shell for boilers from 24 to 78 inches in diameter and from 7 to 20 feet in length. This table also gives in the lower line the area of the head in square feet. Table IX gives the principal facts relating to boiler-tubes of standard sizes, and in the sixth column is given the heating-surface per foot of length. The figure given multiplied by the length of each tube and that result multiplied by the number of tubes will give the heating-surface due to the tubes. In the eighth column

TABLE XI.

TO OBTAIN AREAS TO BE DEDUCTED FROM AREA OF BOILER HEAD FOR VARIOUS SIZES AND NUMBERS OF TUBES.

External Diameter.	1	2	3	4	5	6	7	8	9
1	.0055	.0110	.0165	.0220	.0275	.0330	.0385	.0440	.0495
1¼	.0085	.0170	.0255	.0340	.0425	.0510	.0595	.0680	.0765
1⅜	.0123	.0246	.0369	.0492	.0615	.0738	.0861	.0984	.1107
1¾	.0167	.0334	.0501	.0668	.0835	.1002	.1169	.1336	.1503
2	.0218	.0436	.0654	.0872	.1090	.1308	.1526	.1744	.1962
2¼	.0276	.0552	.0828	.1104	.1380	.1656	.1932	.2208	.2484
2⅜	.0341	.0682	.1023	.1364	.1705	.2046	.2387	.2728	.3069
2¾	.0412	.0824	.1236	.1648	.2060	.2472	.2884	.3296	.3708
3	.0491	.0982	.1473	.1964	.2455	.2946	.3437	.3928	.4419
3¼	.0576	.1152	.1728	.2304	.2880	.3456	.4032	.4608	.5184
3⅜	.0637	.1274	.2011	.2548	.3185	.3822	.4459	.5096	.5733
3¾	.0767	.1534	.2301	.3068	.3835	.4602	.5369	.6136	.6903
4	.0872	.1744	.2616	.3488	.4360	.5232	.6104	.6976	.7848
4⅛	.1104	.2208	.3312	.4416	.5520	.6624	.7728	.8832	.9936
5	.1364	.2728	.4092	.5456	.6820	.8184	.9548	1.0912	1.2276
6	.1963	.3926	.5889	.7852	.9815	1.1778	1.3741	1.5704	1.7667
7	.2673	.5346	.8019	1.0692	1.3365	1.6038	1.9711	2.1384	2.4057
8	.3491	.6982	1.0473	1.3964	1.7455	2.0946	2.4437	2.7928	3.1419
9	.4418	.8836	1.3254	1.7672	2.2090	2.6508	3.0926	3.5344	3.9762
10	.5454	1.0908	1.6362	2.1816	2.7270	3.2724	3.8178	4.3632	4.9086
11	.6600	1.3200	1.9800	2.6400	3.3000	3.9600	4.6200	5.2800	5.9400
12	.7854	1.5708	2.3562	3.1416	3.9270	4.7124	5.4978	6.2832	7.0686
13	.9217	1.8434	2.7651	3.6868	4.6085	5.5302	6.4519	7.3736	8.2953
14	1.0690	2.1380	3.2070	4.2760	5.3450	6.4140	7.4830	8.5520	9.6210
15	1.2202	2.4404	3.6606	4.8808	6.1010	7.3212	8.5414	9.7616	10.9818
16	1.3959	2.7918	4.1877	5.5836	6.9795	8.3754	9.7713	11.1672	12.5631
18	1.7672	3.5344	5.3016	7.0688	8.8360	10.6032	12.3704	14.1376	15.9048
20	2.1814	4.3628	6.5442	8.7256	10.9070	13.0884	15.2698	17.4512	19.6326
22	2.6398	5.2796	7.9194	10.5592	13.1990	15.8398	18.4786	21.1184	23.7582
24	3.1416	6.2832	9.4248	12.5664	15.7080	18.8496	21.9912	25.1328	28.2744

of Table IX will be found the sectional area in square feet of one tube. This figure multiplied by the number of tubes will give the area to be subtracted from one head. This multiplication is tabulated in Table XI for each of the nine digits, and the required figure for any number of tubes can be found readily by shifting the decimal point and adding.

Q. 445 —Example:—Find heating-surface of horizontal boiler 5½ × 17 feet, 70 tubes 4 inches in diameter.

A.—First:—Find heating-surface of shell. $5\frac{1}{2}$ feet equals 66 inches. In Table X under 66 and opposite 17 feet is 146.86, the figure required.

Second:—Find area of tubes. That is, the heating-surface. In Table IX in sixth column opposite 4 inches will be found .977, the heating-surface per foot of length. Multiply this by the number of tubes, 70, and the length of each tube, 17, to get the total heating-surface of the tubes.

$$.977 \times 70 \times 17 = 1162.63.$$

Third:—Find the area of the head. The diameter is 66 inches. In Table X under 66 and in the bottom row of figures, will be found 23.76, the figure desired.

Fourth:—Find the sectional area of 70 tubes. In Table XI under 7 and opposite 4 will be found .6104, which is the area in square feet of 7 tubes 4 inches in diameter. 70 tubes will therefore have an area of 6.104 square feet. But the rule for this type of boiler says that twice the area of the tubes must be deducted from the area of one head. Therefore the last figure, 6.104, must be multiplied by 2, giving 12.208 square feet. The total heating surface is

$$146.86 + 1162.63 + 23.67 - 12.208 = 1320.952 \text{ square feet.}$$

Q. 446—What would be the horse-power of this boiler at 12 square feet per horse power?

A.—$1320.952 \div 12 = 110.08$ horse power.

Q. 447—You have said that the water line should be above the top row of tubes; and, as this row is above the center line of the boiler, is it not erroneous to assume, as you have in the rules, that only half of the head is effective?

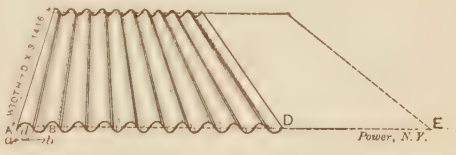


FIG. 55.

A.—Yes. But in a 60 inch boiler with the water line 7 inches above the center line the error is less than $\frac{1}{2}$ a horse power; and in the case just calculated it is about $2\frac{1}{2}$ per cent. The calculation of the segment is too long and tedious, and is a refinement not necessary in this work, which is only an approximation. Neither is it of any consequence to take care of the decimals of a foot of heating-surface.

Q. 448—Give a rule for finding the heating-surface of a corrugated flue.

A.—Multiply the average diameter by the length of the flue, both in feet, and the product by 4.93. The result will be the square feet of heating-surface.

Q. 449.—Show how this rule is obtained.

A.—Suppose you cut the flue longitudinally and straightened it out, as shown in Fig. 55, you would have a sheet of corrugated metal the width of which would be the mean circumference of the tube, i. e., D $\times$ 3.1416 where D = the mean diameter. Now, what would be its length if it were straightened out flat? Each corrugation is practically a half circle to either side of the mean diameter, so that the length of sheet from A to B is the same as the circumference of the circle having a diameter D; i. e., D $\times$ 3.1416, but the length which it really occupies; i. e., the corresponding length of a flue, is $a\ b = 2$ D. The length of the sheet is therefore to the length of the tube as 3.1416 is to 2 or the length A E of the straightened sheet would be

$$\frac{3.1416 \times L}{2}$$

where L equals the length A D of the corrugated flue. Since the surface is the length multiplied by the width we have for the area

$$\frac{3.1416 \times L}{2} \times D \times 3.1416 \text{ or } \frac{3.1416^2 DL}{2} = 4.93.\ DL$$

SECTION VIII.

The Safety-Valve.

Q. 450—What is the United States marine rule for determining the area of lever safety-valves for marine-boilers?

A.—*"Lever safety-valves to be attached to marine boilers shall have an area of not less than one square inch to every two square feet of the grate-surface in the boiler, and the seats of all such safety-valves shall have an angle of inclination of 45° to the center line of their axis."*

Q. 451—How many square feet of grate surface are allowed per square inch of area with spring loaded safety-valves constructed so as to give an increased lift by the operation of steam?

A.—Three.

Q. 452—What is the best method of determining the size of safety-valve required for a boiler under given conditions?

A.—Find how much water the boiler can possibly evaporate under the given conditions by multiplying the greatest amount of coal which can possibly be burned per square foot of grate per hour under the given conditions by the grate-surface in square feet and by the greatest number of pounds of water which each pound of coal would evaporate; and provide valve area to amply allow of the discharge of that amount.

AREA AND DIAMETER OF VALVE REQUIRED.

Q. 453— How do you find the necessary area of opening?

A.—*Multiply the absolute pressure at which the value is to be set by 51, and divide the number of pounds of steam possible to be generated per hour, determined as above, by the product.*

Q. 454—How do you find the area of opening afforded by a flat-seated valve?

A.—*Multiply the diameter of the opening in valve by 3.1416 and by the lift.*

Q. 455—How do you find the diameter of a flat valve necessary to give a certain area?

A.—*Divide the given area by the product of the lift and by 3.1416.*

Q. 456—What must the lift be in order that the area for escape may equal the area of a flat-seated valve?

A.—One fourth of the diameter.

Q. 457—How do you find the amount of opening afforded by a bevel-seated valve for a lift less than the depth of the seat?

A.—*(1) Multiply the diameter of the valve by 3.1416, by the lift and by the sine of the angle of the seat; (2) Multiply the square of the lift by the square of the sine of the angle of the seat, by the cosine of this angle, and by 3.1416; (3) add the two products.*

FIG. 56.

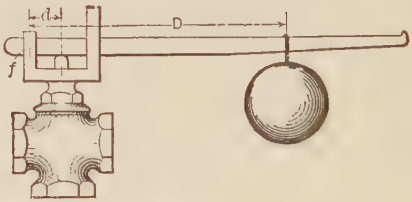


FIG. 57.

Q. 458—How do you find the area of opening afforded by a valve having a 45° seat, as required by the marine rule, and lifting less than the depth of the seat?

A.—*Multiply the diameter of the valve by the lift and by 2.22; (2) Multiply the square of the lift by 1.11; add the two products.*

Q. 459—How do you find the area of opening when the seat is beveled 30° and the lift is less than the depth of the seat?

A.—*(1) Multiply the diameter of the valve by the lift and by 1.57; (2) Multiply the square of the lift by .68; (3) add the two products.*

Q. 460—How do you find the area of opening when the depth of the bevel is so slight that the valve lifts clear of it?

A.—*Compute the opening for a beveled valve with a lift equal to the depth of the seat, and for a flat valve with the remainder of the lift, and add the results.*

Q. 461—What is the force tending to lift or open a safety-valve?

A.—The product of the area of the valve by the pressure per unit of area.

Q. 462—How is this force resisted?

A.—By loading the valve with weights, as in Fig. 56; by a spring, or by a smaller weight applied through a lever, as in Fig. 57.

Q. 463—What do you understand by the "fulcrum" of a lever-valve?

A.—The pin or point upon or about which the lever turns (see *f* in Fig. 57).

Q. 464—What is the principle of the lever?

A.—That the product of one force and its distance from the fulcrum is equal to the product of the opposing force and its distance from the fulcrum.

Q. 465—How does this apply to the lever safety-valve?

A.—The product of the upward force and its distance from

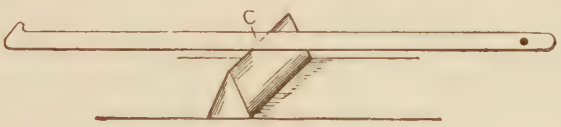


FIG. 58.

the fulcrum is equal to the sum of the products of the downward forces and their respective distances from the fulcrum.

Q. 466—What are the downward forces?

A.—The weight of the valve and stem, the weight of the lever, and the weight of the ball.

Q. 467—How is the distance of the valve and ball from the fulcrum measured?

A.—Horizontally between perpendicular lines passing through the center of each (see *d* and *D*, Fig. 57).

Q. 468—How does the lever act?

A.—As though its entire weight were concentrated at its center of gravity.

Q. 469—How do you find the center of gravity?

A.—By balancing the lever over a sharp edge (as in Fig. 58). The center of gravity will be over the edge (as at *C*) when the lever balances.

Q. 470—In this operation do you allow anything for the metal back of the fulcrum? In other words, would you pro-

ceed any differently if the lever projected six inches back of the fulcrum?

A.—No. It takes care of itself by bringing the center of gravity nearer to the fulcrum. If the lever were prolonged behind the fulcrum until the fulcrum and center of gravity were in the same spot, the lever would simply balance over the pivot and not bear on the stem. Its effect is zero. So is the product of its weight *W* and the distance o between the center of gravity and the fulcrum.

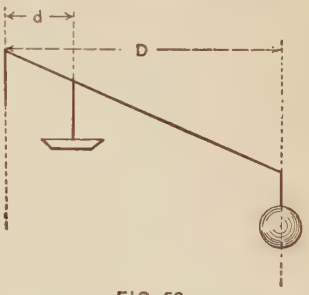


FIG. 59.

Q. 471—In determining, then, the effect of the lever in holding down the valve, how do you proceed?

A.—Multiply the weight of the lever by the distance of its center of gravity from the fulcrum in a horizontal line.

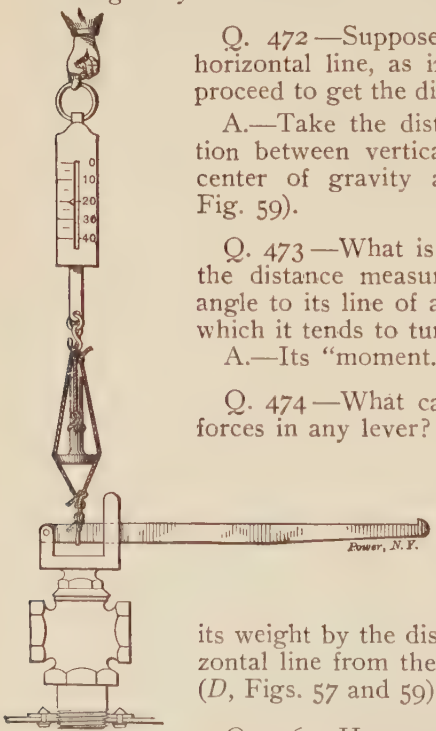


FIG 60.

Q. 472—Suppose the lever were out of a horizontal line, as in Fig. 59, how would you proceed to get the distance?

A.—Take the distance in a horizontal direction between vertical lines drawn through the center of gravity and the fulcrum (as *D d* Fig. 59).

Q. 473—What is the product of a force and the distance measured in this way at a right angle to its line of action, from the point about which it tends to turn an object called?

A.—Its "moment."

Q. 474—What can you say of the opposing forces in any lever?

A.—Their moments must be equal.

Q. 475—How do you determine the moment of the ball?

A.—By multiplying its weight by the distance of its center in a horizontal line from the vertical line of the fulcrum (*D*, Figs. 57 and 59).

Q. 476—How may the effective weight at the point of application of the lever, valve, and stem be determined experimentally?

A.—By attaching a spring balance to the lever at the point where it bears on the stem, attaching the valve and stem, and ascertaining their combined weight at this point, as in Fig. 60.

When the Effective Weight of the Valve, Stem and Lever is Given.

TO FIND THE PRESSURE.

Q. 477—How would you find the pressure at which a valve would lift with a given weight at a given distance from the fulcrum, the effective weight (w) of the valve, stem and lever determined as in Fig. 60?

A.—By the following—Rule:—*Multiply the weight by its distance from the fulcrum. Multiply the weight of the valve and lever by the distance of the stem from the fulcrum, and add this to the former product. Divide the sum of the two products by the product of the area of the valve multiplied by its distance from the fulcrum, and the result will be the pressure in pounds.*

Formula: $$\frac{WD + wd}{Ad} = P$$

Where A = Area of valve in square inches;
D = Distance of ball from fulcrum;
d = Distance of valve stem from fulcrum;
P = Pressure at which valve will lift;
W = Weight of ball;
w = Effective weight of lever, valve and stem.

Example:—At what pressure will a 3-inch valve blow off with valve stem 3 inches from fulcrum and having a lever, valve and stem which have an effective weight, determined, as shown in Fig. 60, of 20 pounds, and a 48-pound ball 24 inches from the fulcrum?

$A = 3 \times 3 \times .7854 = 7.0686$ $\quad$ $d = 3$
$D = 24$ $\quad$ $w = 20$
$W = 48$

$$\frac{48 \times 24 + 20 \times 3}{7.0686 \times 3} = 57.15 \text{ pounds.}$$

TO FIND THE DISTANCE OF WEIGHT FROM FULCRUM.

Q. 478—How would you find the distance from the fulcrum at which the weight would have to be placed in the above example in order that the valve might blow off at 70 pounds?

A.—To find the distance of ball from fulcrum for a required pressure apply the following—

RULE:—*Multiply the area of the valve by the pressure, and from the product subtract the effective weight of the valve and lever. Multiply the remainder by the distance of stem from fulcrum, and divide by the weight of the ball. The quotient will be the required distance.*

FORMULA:— $$\frac{(A\ P - w)\ d}{W} = D$$

SOLUTION:— $$\frac{(7.0686 \times 70 - 20) \times 3}{48} = 29.6 \text{ inches.}$$

TO FIND THE WEIGHT REQUIRED.

Q. 479—How would you find the weight required to allow the valve to blow off at 70 pounds when located 24 inches from the fulcrum?

A.—To find the weight required to balance a given pressure at a given distance from the fulcrum, apply the following—

RULE:—*Multiply the area of the valve by the pressure, and from the product subtract the effective weight of the valve and lever. Multiply the remainder by the distance of stem from fulcrum, and divide by the distance of ball from fulcrum. The quotient will be the required weight.*

FORMULA:— $$\frac{(A\ P - w)\ d}{D} = W$$

SOLUTION:— $$\frac{(7.0686 \times 70 - 20) \times 3}{24} = 59.3 \text{ pounds.}$$

TO FIND THE EFFECTIVE WEIGHT OF THE LEVER, VALVE AND STEM.

Q. 480—If you had no scales, how could you calculate the effective weight?

A.—*Multiply the actual weight of the lever by the distance between its center of gravity and the fulcrum, and divide by the distance between the fulcrum and the stem. To the quotient add the actual weight of the valve and the stem.*

When the Effective Weight of the Valve, Stem and Lever is not Known.

TO FIND THE PRESSURE.

Q. 481.—In the three examples given above it has been assumed that the "effective" weight of the lever, weighed at the point of application of the valve stem, was known. How would you determine the pressure at which a 3-inch valve would blow off with the stem 3 inches from the fulcrum, valve and stem weighing 1½ pounds, lever weighing 6 pounds, having its center of gravity 15 inches from the fulcrum, and weighted with a 48 pound ball 24 inches from the fulcrum?

A.—By the principle of the lever the sum of the moments of the downward forces must equal the moment of the upward force.

Let A = area of valve;
D_v = its distance from fulcrum;
W_v = weight of valve and stem;
W_l = weight of lever;
D_l = distance of its centre of gravity from fulcrum;
P = pressure in lbs. per sq. in.;
W_b = weight of ball;
D_b = distance of ball from fulcrum; then

$$W_v \times D_v + W_l \times D_l + W_b \times D_b = A \times P \times D_v$$

and $$\frac{W_v \times D_v + W_l \times D_l + W_b \times D_b}{A \times D_v} = P$$

Rule:—*Multiply the weight of the valve, the lever and the ball each by the distance of its center of gravity from the fulcrum and add the products. Divide the sum by the product of the area of the valve and the distance of its stem from the fulcrum. The quotient will be the pressure.*

Operation:— $\frac{1.5 \times 3 + 6 \times 15 + 48 \times 24}{7.0686 \times 3} = 58.7$ lbs.

$1.5 \times 3 = 4.5$
$6 \times 15 = 90.$
$48 \times 24 = 1152.$
$7.0686 \times 3 = 21.2058$) 1246.5
587 pounds.

TO FIND THE DISTANCE FROM FULCRUM.

Q. 482.—At what distance from the fulcrum would the weight in the above example require to be placed to allow the valve to lift at 70 pounds?

A.—To find the distance of ball from fulcrum apply the following

RULE:—*Multiply the area of the valve by the pressure and by the distance of the valve stem from the fulcrum (Product 1).*

Multiply the weight of the valve by the distance of its stem, and the weight of the lever by the distance of its center of gravity, from the fulcrum. Add the two products, and subtract the sum from Product 1.

Divide the remainder by the weight of the ball, and the quotient will be the distance of ball from fulcrum required.

$$\text{FORMULA:} \frac{A\ P\ D_v - (W_v \times D_v + W_l \times D^l)}{W_b} = D_b$$

$$\text{SOLUTION:} \frac{7.0686 \times 70 \times 3 - (1.5 + 3 + 6 \times 15)}{48} =$$

$$\frac{1484.406 - (4.5 + 90)}{48} = 29 \text{ inches.}$$

TO FIND THE WEIGHT OF BALL REQUIRED.

Q. 483.—How would you find the weight of ball required for the valve to lift at 70 pounds when the ball was distant 24 inches from the fulcrum?

A.—By using the last rule, and dividing the remainder in the last paragraph by the given distance instead of the weight.

Q. 484.—How would you proceed in case there were two weights?

A.—Treat the additional weight just as you would the weight of the lever, adding or subtracting the weight multiplied by its distance from the fulcrum wherever the weight of the lever multiplied by the distance of its center of gravity is added or subtracted in the above rules.

SECTION IX.

Chimneys.

Q. 485.—What makes a chimney draw?

A.—The difference between the weight of the column of heated gases within and an equal column of the cooler air without.

Q. 486.—Upon what does the capacity of a chimney depend?

A.—Upon its height, cross-sectional area, and temperature of gases.

Q. 487.—What is the effect of increasing the height of the chimney?

A.—It increases the intensity of the draft, because it makes a greater difference per unit of base between the weight of the inside column and a column of equal height of the outside air.

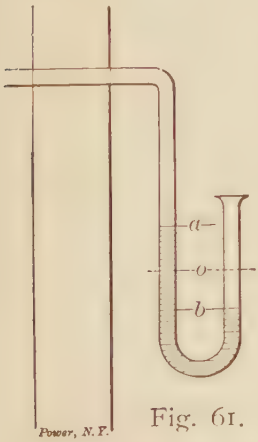


Fig. 61.

Q. 488.—How is the difference in pressure measured?

A.—By the height of a column of water which it will support. A U-tube has one leg connected with the inside of the chimney and the other open to the air, as in Fig. 61. The greater pressure of the atmosphere pushes the water toward the chimney until the difference in the heights of the columns in the glass tube is sufficient to balance the difference in pressure between the flue and atmosphere. The pressure is measured by the *difference* between the heights of the col-

umns, i. e., the distance *ab*, not the height of one column above the zero mark, as *oa*.

Q. 489—What is a common draft of chimneys as measured in inches of water?

A.—About $\frac{1}{2}$ inch for ordinary heights and temperatures.

Q. 490—What is the effect of an increase in this difference of pressure or intensity of draft?

A.—To increase the velocity with which the gases flow through the chimney.

Q. 491—Is this increase in velocity proportional to the increase in pressure, i. e., will increasing the pressure from $\frac{3}{8}$ of an inch of water to $\frac{3}{4}$ of an inch double the velocity?

A.—No; the velocity increases as the square root of the pressure. In order to double the velocity the pressure would have to be made 4 times as great; to get 3 times the velocity would require 9 times the pressure.

Q. 492—Does the pressure vary directly as the height of the chimney, i. e., if you double the height do you double the intensity of the draft?

A.—Yes.

Q. 493—And how much would you increase the velocity?

A.—The square root of 2 times, which is 1.414 times.

Q. 494—Explain why this is so.

A.—The velocity of flow will be theoretically that velocity which a body would gain in falling from the top of a column of air high enough to give the given pressure per unit of base. This velocity is approximately 8 times the square root of the height of the column, $v^2 = 2\,gh$.

Q. 495—Then what relation has the height of a chimney to its capacity?

A.—Its capacity varies as the square root of the height. In a chimney 200 feet high the velocity will be theoretically twice that in a 50-foot chimney, so that twice as much gas would be discharged in a given time.

Q. 496—What relation has the area of a chimney to its capacity?

A.—The capacity varies directly as the area, i. e., a chimney of twice the cross section will discharge twice the, amount of gas in a given time.

Q. 497—How does the area increase?

TABLE XII.

GIVING AREA OF CHIMNEY IN SQUARE INCHES WHEN CONNECTED TO GRATE SURFACES FROM 25 TO 1000 SQUARE FEET, FOR DIFFERENT HEIGHTS OF CHIMNEYS.

Square feet of Grate Surface.	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	Square feet of Grate Surface.
25	387	372	358	346	335	325	316	307	300	292	286	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	25
50	774	744	717	692	670	650	632	615	600	585	57	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	50
75	1,161	1,116	1,055	1,039	1,006	976	948	923	900	878	858	839	.....	.....	.....	.....	.....	.....	.....	.....	.....	75
100	1,549	1,488	1,434	1,385	1,341	1,301	1,264	1,231	1,200	1.171	1,144	1,119	.....	.....	.....	.....	.....	.....	.....	.....	.....	100
125	1,936	1,860	1,792	1,732	1,677	1,626	1,581	1,538	1,500	1,463	1,430	1,398	1,369	.....	.....	.....	.....	.....	.....	.....	.....	125
150	2,322	2,232	2,151	2,078	2,012	1,952	1,897	1,846	1,800	1,756	1,716	1,678	1,643	1,609	.....	.....	.....	.....	.....	.....	.....	150
175	2,711	2,604	2,509	2,424	2,347	2,277	2,213	2,154	2,100	2,049	2,002	1,958	1,917	1,878	1,841	.....	.....	.....	.....	.....	.....	175
200	3,098	2,976	2,868	2,771	2,683	2,603	2,529	2,462	2,400	2,342	2,288	2,238	2,190	2,146	2,104	2,065	.....	.....	.....	.....	.....	200
225	3,485	3,348	3,227	3,117	3,018	2,928	2,846	2,770	2,700	2,634	2,574	2,517	2,464	2,314	2,368	2,323	.....	.....	.....	.....	.....	225
250	3,873	3,721	3,585	3,464	3,354	3,253	3,162	3,077	3,000	2,927	2,860	2,797	2,738	2,683	2,631	2,582	2,535	2,491	.....	.....	.....	250
275	4,260	4,093	3,944	3,810	3,689	3,579	3,478	3,385	3,300	3,220	3,146	3,077	3,012	2,951	2,894	2,840	2,789	2,740	.....	.....	.....	275
300	4,647	4,465	4,302	4,157	4,024	3,904	3,794	3,693	3,600	3,513	3,432	3,357	3,286	3,219	3,157	3,098	3,042	2,989	2,939	.....	.....	300
325	5,034	4,837	4,661	4,503	4,360	4,230	4,110	4,001	3,900	3,801	3,718	3,636	3,560	3,488	3,420	3,356	3,296	3,238	3,184	3,132	.....	325
350	5,422	5,209	5,019	4,849	4,695	4 555	4,427	4,309	4,200	4,098	4,001	3,916	3,834	3,756	3,683	3 614	3,459	3,487	3,429	3,373	3,320	350
375	.....	5,581	5,378	5,196	5,031	4,880	4,743	4,616	4,5 0	4 391	4,290	4,196	4,107	4,024	3,946	3,873	3,803	3,737	3 674	3,614	3.557	375
400	.....	.....	5,737	5.542	5,366	5,206	5.059	4 924	4,800	4,684	4,576	4,476	4,381	4,293	4,209	4,131	4,056	3,986	3 919	3,855	3,794	400
425	.....	.....	.....	5 889	5.702	5,531	5,375	5,232	5,100	4,977	4,862	4,755	4,655	4 561	4,473	4,389	4,310	4 235	4.164	4.096	4,031	425
450	.....	.....	.....	.....	6,037	5,857	5,692	5,540	5,400	5,269	5,148	5,035	4,929	4,829	4,736	4,647	4,563	4,484	4,409	4,337	4,269	450
475	.....	.....	.....	.....	6,372	6,182	6,208	5,848	5,700	5,562	5,434	5 315	5,203	5,098	4,999	4,905	4,817	4,733	4,654	4,578	4,506	475
500	.....	.....	.....	.....	.....	6,507	6,324	6,155	6,000	5 855	5,720	5,595	5,477	5,366	5,262	5,164	5,070	4,982	4,899	4,819	4,743	500
525	.....	.....	.....	.....	.....	6,832	6,640	6,463	6,300	6,148	6 006	5,874	5,751	5,634	5,525	5 422	5,325	5,231	5,143	5,060	4,980	525
550	.....	.....	.....	.....	.....	7,1 8	6,957	6,771	6 600	6 440	6 292	6,154	6,024	5,903	5,788	5,680	5,578	5,481	5.388	5.301	5,217	550
575	.....	.....	.....	.....	.....	.....	7,273	7,079	6,900	6,733	6,578	6 434	6,298	6,171	6,051	5,938	5,831	5,730	5,633	5,542	5,454	575
600	.....	.....	.....	.....	.....	.....	7,389	7,387	7,200	7,026	6,864	6,714	6,572	6,439	6,314	6,169	6,085	5,979	5,878	5,783	5,692	600
625	.....	.....	.....	.....	.....	.....	7 905	7,694	7,500	7,319	7,151	6,994	6,846	6 708	6,577	6,455	6,338	6,228	6,123	6,024	5,929	625
650	.....	.....	.....	.....	.....	.....	8,221	8,002	7,800	7,612	7,437	7,273	7,120	6,976	6,841	6,713	6,592	6,477	6,368	6,265	6,166	650
675	.....	.....	.....	.....	.....	.....	.....	8,310	8,100	7,904	7,723	7,553	7,394	7,244	7,104	6,971	6,845	6 726	6,613	6,506	6,403	675
700	.....	.....	.....	.....	.....	.....	.....	8,618	8,400	8,197	8,009	7,833	7,668	7,513	7,367	7,229	7,099	6 975	6,858	6 747	6,640	700
725	.....	.....	.....	.....	.....	.....	.....	8,926	8,700	8,490	8,295	8,112	7,942	7 781	7,630	7,487	7,352	7 225	7.103	6,988	6,877	725
750	.....	.....	.....	.....	.....	.....	.....	9 233	9,000	8,783	8,581	8 392	8,215	8 049	7,893	7,746	7 606	7,474	7 348	7,229	7,115	750
775	.....	.....	.....	.....	.....	.....	.....	9,540	9,300	9,075	8,867	8,672	8,489	8,318	8 156	8,004	7,859	7,723	7,593	7,469	7,352	775
800	.....	.....	.....	.....	.....	.....	.....	.....	9,600	9,368	9,153	8 952	8 763	8 586	8,419	8,262	8,113	7,972	7,838	7,710	7,589	800
825	.....	.....	.....	.....	.....	.....	.....	.....	9,900	9,661	9,439	9,231	9 037	8,854	8,682	8,520	8,367	8,221	8,083	7,951	7,826	825
850	.....	.....	.....	.....	.....	.....	.....	.....	10 200	9,954	9,725	9,511	9,311	9,123	8,946	8,778	8,620	8 470	8,328	8,192	8,063	850
875	.....	.....	.....	.....	.....	.....	.....	.....	10.500	10 246	10,011	9 791	9,585	9,391	9 209	9 037	8,874	8 719	8,573	8,433	8,300	875
900	.....	.....	.....	.....	.....	.....	.....	.....	10.800	10,539	10 297	10,071	9,859	9,659	9 472	9,295	9 127	8,968	8,818	8,674	8,538	900
925	.....	.....	.....	.....	.....	.....	.....	.....	11,100	10,832	10,583	10,350	10,132	9 928	9 735	9,553	9,381	9 218	9,063	8,915	8,775	925
950	.....	.....	.....	.....	.....	.....	.....	.....	11,400	11,125	10,869	10,630	10,406	10 196	9,998	9,811	9 634	9,467	9,308	9,156	9,012	950
975	.....	.....	.....	.....	.....	.....	.....	.....	11,700	11,418	11,155	10,910	10,680	10,464	10,261	10,069	9,888	9,716	9,553	9 397	9,249	975
1000	.....	.....	.....	.....	.....	.....	.....	.....	12.000	11,710	11,441	11,190	10,954	10,733	10,524	10,328	10,141	9,965	9,798	9,638	9,486	1000

A.—As the square of the diameter.

Q. 498—Give then a general statement for the capacities of chimneys.

A.—The capacity varies as the square root of the height and as the square of the diameter.

Q. 499—What is the effect of temperature on the capacity of a chimney.

A.—The greater the inside temperature the greater the difference in pressure and *velocity* of the gases; but as the density of the gases decreases with the temperature there is a point where as much is lost in *weight* of gas passed by the lightness of the gas as is gained by the increased velocity.

Q. 500—Then the intensity of the draft as measured by the U-tube is not a measure of the *capacity* of a chimney?

A.—No; the capacity *for the same temperature* (as where the greater intensity is gained by an increase in height) is as the square root of the intensity. But suppose we raise the temperature so as to double the volume of the gas. This would double the intensity of the draft and increase the velocity 1.41 times; but the velocity would need to be increased 2 times to pass the doubled volume in the same time.

Q. 501—How would you find the area required in a chimney for a given height and number of square feet of grate-surface connected?

A.—*Multiply the number of square feet of grate-surface by 120 and divide by the square root of the height. The quotient will be the required cross-section in square inches.* (See Table XII.)

Q. 502—How could the area required for a given horse-power be determined?

A.—By the above rule, for which John T. Henthorn, M. E., is responsible, allowing three horse-power per square foot of grate.

Or by the following rule which was proposed by William Kent, M. E.

Divide the horse-power by 3.33 times the square root of the height. The quotient will be the required effective area in square feet. To the diameter or length of side required to give this area add 4 inches to compensate for friction.

Q. 503—What is Kent's formula based on?

A.—It assumes that the coal consumption is 5 pounds per hour per horse-power. The draft power of the chimney varies as the square root of the height. The retarding of the ascending gases by friction may be considered as equivalent to a dimi-

nution of the area of the chimney, or to a lining of the chimney by a layer of gas which has no velocity. This layer is assumed to be 2 inches thick, so that for round chimneys the effective area is equal to the area of a circle whose diameter is 4 inches less than the actual diameter. For square chimneys, the effective area is that of a square whose side is 4 inches less than the inside measurement of the chimney. It is also as-

TABLE XIII. — HORSE POWER OF CHIMNEYS.

Diameter, Inches.	Area A, Square ft.	Effective area. $E = A - 0{\cdot}6\sqrt{A}$. Square feet.	Formula H.-P. $= 3{\cdot}33\,(A - 0{\cdot}6\sqrt{A})\sqrt{h}$. Height of chimney. 50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	Equivalent square chimney. Side of square $\sqrt{E} + 4$ inches.
			Commercial horse-power of boiler.											
18	1·77	·97	23	25	27	..	..	..	..	..	..	..	..	16
21	2·41	1·47	35	38	41	..	..	..	..	..	..	..	..	19
24	3·14	2·08	49	54	58	62	..	..	..	..	..	..	..	22
27	3·98	2·78	65	72	78	83	..	..	..	..	..	..	..	24
30	4·91	3·58	84	92	100	107	113	..	..	..	..	..	..	27
33	5·94	4·48	..	115	125	133	141	..	..	..	..	..	..	30
36	7·07	5·47	..	141	152	163	173	182	..	..	..	..	..	32
39	8·30	6·57	..	..	183	196	208	219	..	..	..	..	..	35
42	9·62	7·76	..	..	216	231	245	258	271	..	..	..	..	38
48	12·57	10·44	..	..	..	311	330	348	365	389	..	..	..	43
54	15·90	13·51	..	..	..	..	427	449	472	503	551	..	..	48
60	19·64	16·98	..	..	..	..	536	565	593	632	602	748	..	54
66	23·76	20 83	..	..	.	..	..	694	728	776	849	918	981	59
72	28·27	25·08	..	..	..	..	..	835	876	934	1,023	1,105	1,181	64
78	33·18	29·73	..	..	..	..	..	..	1,038	1,107	1,212	1,310	1,400	70
84	38·48	34·76	..	..	..	..	..	..	1,214	1,294	1,418	1,531	1,637	75
90	44·18	40·19	..	..	..	..	..	..	..	1,496	1,639	1,770	1,893	80
96	50·27	46·01	..	..	..	..	..	..	..	..	1,876	2,027	2,167	86

sumed that the power varies directly as the effective area; that is, if a chimney is designed by this rule to take care of 100 horse-power, and the coal consumption is reduced from 5 pounds per hour per horse-power to 4 pounds, the chimney will then be large enough to take care of $100 \times 5 \div 4 = 125$ horse-power.

Q. 504 —How would you find the horse-power of a chimney of a given height and area?

A.—*From the area in square feet subtract .6 of the square root of that area, and multiply the remainder by the square root of the height and by 3.33. The result is the horse-power based on a coal consumption of 5 pounds per hour per horse-power.*

Expressed in the shape of a formula, this is:

$$P = 3.33\ (A - .6\sqrt{A})\ \sqrt{H}.$$

where

P = horse-power.
A = area of chimney in square feet.
H = height of chimney, in feet.

Table XIII gives the results obtained by this formula for various diameters and heights.

If the coal consumption is reduced to 4 pounds per hour per horse-power, the capacity of a given chimney may be found in Table XIV, which was calculated on that assumption from Kent's rule.

For any other coal consumption the capacity may be found by multiplying the capacity given in either Table XIII or Table XIV by the ratio of the consumption of the table to the given consumption. That is for a 2 pound consumption the values in Table XIII would be multiplied by $5 \div 2 = 2.5$, and the values in Table XIV by $4 \div 2 = 2$.

Another method of finding the power is that given by Henthorn. *Multiply the area in square inches by the square root of the height in feet and divide by 40. The quotient will be the horse-power.*

Q. 505—What considerations govern the height of a chimney?

A.—It must be high enough to give the required intensity of draft, at an economical flue temperature, and to be well above surrounding objects; but these objects attained, increased capacity is much more cheaply gained by increasing the area, as it is cheaper to build nearer the ground, and the capacity increases as the square of the diameter and only as the square root of the height. If of brick, the height should not exceed ten or eleven times the base, on account of stability.

Q. 506—How do you find the difference in pressure to be expected between the inside and outside of a chimney for a given height and temperature?

A.—*Divide 39 by the absolute (actual temperature Fahrenheit + 461) temperature of the outside air; again, divide 40 by the absolute average temperature of the gases in the stack.*

Subtract the latter from the former quotient, multiply the remainder by the height of the chimney in feet, and divide by 5.2

TABLE XIV.

COMMERCIAL HORSE POWER OF CHIMNEYS—BASED ON COAL CONSUMPTION OF 4 LBS.

Clear Diam. (inches)	Effective Diam. (inches)	Effective Area (sq. ft.)	HEIGHT IN FEET. 50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
			Draft in inches of water.—Internal Air, 400° F. External, 70°.															
			.257	.308	.359	.410	.462	.513	.564	.616	.667	.718	.769	.821	.872	.923	.975	1.026
			HORSE POWER.															
28	24	3.14	92	101	109	117												
32	28	4.28	126	138	149	159												
36	32	5.58	164	180	194	208	221											
40	36	7.07	203	228	246	263	279											
44	40	8.73	257	282	304	325	345	364										
48	44	10.56	311	341	368	393	417	440	461									
52	48	12.57		406	438	468	497	524	549									
56	52	14.75		476	514	549	583	615	644	675								
62	58	18.35			640	683	725	764	802	840	872							
68	64	22.65			790	844	895	944	990	1037	1076	1116						
74	70	26.73				996	1056	1114	1168	1224	1270	1317	1364					
80	76	31.50				1173	1245	1312	1376	1443	1496	1552	1607	1660				
86	82	36.68					1450	1528	1603	1680	1742	1808	1872	1933	1993			
92	88	42.24					1659	1760	1846	1935	2006	2082	2155	2226	2295	2362		
98	94	48.20						2008	2106	2208	2289	2375	2459	2540	2619	2695	2767	
104	100	54.52						2273	2382	2497	2589	2687	2782	2873	2962	3049	3130	3212
116	112	68.42							2990	3134	3250	3372	3491	3605	3717	3826	3928	4030
128	124	83.86							3664	3841	3983	4133	4279	4419	4556	4683	4814	4940
140	136	100.90										4973	5149	5318	5482	5642	5792	5944
152	148	119.50											6098	6298	6492	6682	6860	7040
164	160	139.60											7124	7357	7584	7808	8014	8224
176	172	161.40											8236	8506	8770	9026	9266	9508
188	184	184.70											9424	9733	10030	10330	10600	10880
200	196	209.50											10690	11040	11380	11715	12030	12340
	Height in Feet.		50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200

FORMULA.
$4.166\ E.A. \sqrt{H}$
For 5 lb. coal consumption multiply values by $\frac{5}{10}$.

The final quotient will be the draft in inches of water.

The formula is as follows:

$$P = \frac{H}{5.2}\left(\frac{39}{Ta} - \frac{40}{Ts}\right)$$

Table XIV shows the values obtained by this formula for an average stack temperature of 400° and an external temperature of 70°, for various heights.

Q. 507.—Is the average temperature of the stack in the above rule the average temperature of the gases going to the stack, or the average temperature of the flue itself?

A.—The average temperature of the column in the stack, taking account of loss by radiation.

SECTION X.

Steam piping.

Q. 508—Is steam-pipe rated by its outside or inside diameter?

A.—The inside diameter comes nearest to the rating, but even this is greater than the normal, especially in the smaller sizes (see Table XV).

Q. 509—How do you determine the capacity in horse-power for a given size of pipe for simple engines?

A.—*Multiply the square of the diameter by 6.*

Q. 510—For example, what number of horse-power would a 5-inch pipe supply.

A.—$5 \times 5 \times 6 = 150$ horse-power.

Q. 511—How do you find the size of pipe required to supply a given horse-power?

A.—*Divide the horse-power by 6 and use the commercial size of pipe nearest the square root of the quotient.*

Q. 512—For example, what size of pipe is required to supply a 600 horse-power engine?

A.—$600 \div 6 = 100$, and the square root of 100 = 10-inch pipe.

Q. 513—What is the requirement to be met in determining the size of steam-mains?

A.—That the velocity of the steam shall not exceed 6,000 feet per minute.

Q. 514—Upon what is the above rule based?

A.—Upon general practice, having a due regard for the above stated requirement.

Q. 515—How can you determine the size of pipe required for a given size cylinder?

A.—*Multiply the cross-sectional area of the cylinder by the piston speed in feet per minute and divide by 6,000.*

Q. 516—Inasmuch as less steam is required per horse-power for an automatic cut-off than for a throttling engine, does not the latter require a larger supply pipe per horse-power than the former?

A.—No. The flow of steam is so much more uniform in an engine where the admission line extends through the greater part of the stroke that the same size used for the automatics will supply the greater amount of steam used by the throttling engines, because it is in use a greater proportion of the time. There is no use in furnishing an extra large pipe to keep up the pressure against a governor which is going to throttle it anyway.

Q. 517—Is the same size of pipe used for condensing and non-condensing engines, notwithstanding the difference in the amount of steam required?

A.—Yes, generally. If the cylinder develops the same amount of power condensing as it would non-condensing the cut-off would be earlier, and a shorter time will be allowed for the flow, and in case of accident to the condenser or failure of the water supply the engine will have to run non-condensing anyway. The engine builder, moreover, does not know in most instances whether the engine will run condensing or not, and always puts the same size of flange on a given size of cylinder.

Q. 518—What about the size of pipe required by compound and triple expansion engines?

A.—Make the pipe large enough to supply the high pressure cylinder.

Q. 519—How does the cross-sectional area of a pipe vary?

A.—As the square of the diameter, i. e., doubling the diameter increases the area 4 times. Decreasing the diameter to one-third reduces the area to one-ninth.

Q. 520—How do you find the area of a pipe?

A.—Multiply the square of the internal diameter by .7854.

Q. 521—Does the rule given above for engine supply pipes allow for the friction in ordinary distances between engine and boiler?

A.—It does.

Q. 522—What are the objections to unnecessarily large mains?

A.—Increased first cost of pipe, erection, and covering; increased difficulty of supporting and providing for the expansion of the main, and increased loss by radiation.

Q. 523—What practice is recommended when the distance between the engine and boiler is excessive?

A.—In such cases a receiver of considerably capacity should be located near the engine, and serve as the direct source of supply to the cylinder, the receiver being supplied by the main leading from the boilers.

Q. 524—What purpose does the receiver serve?

A.—It provides a volume of steam close at hand sufficient to furnish a charge of steam to the cylinder without serious reduction of pressure, the supply to the receiver being made up by the continued flow after cut-off, the flow through the main being thus rendered more continuous and with a lower maximum velocity; so that a smaller pipe may be used without great loss of pressure. The volume of the receiver affords also an opportunity for the separation of water in the steam, and thus serves as a safeguard against water in the engine.

TABLE XV.

STANDARD SIZES, ETC., OF WROUGHT-IRON PIPE.

For Water, Gas or Steam.

(Briggs Standard.)

Diameter of Tube.								Sectional Area	
Nominal Inside.	Actual Inside.	Actual Outside.	Thickness of Metal.	Internal Circumference.	External Circumference.	Length of Pipe per Sq. Ft. of Inside Surface.	Length of Pipe per Sq. Ft. of Outside Surface.	Internal.	External.
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Feet.	Feet.	Ins.	Ins.
⅛	.270	.405	.068	.848	1.272	14.15	9.44	.0572	.129
¼	.364	.540	.088	1.144	1.696	10.50	7.075	.1041	.229
⅜	.494	.675	.091	1.552	2.121	7.67	5.657	.1916	.358
½	.623	.840	.109	1.957	2.652	6.13	4.502	.3048	.554
¾	.824	1.050	.113	2.589	3.299	4.635	3.637	.5333	.866
1	1.048	1.315	.134	3.292	4.134	3.679	2.903	.8627	1.357
1¼	1.380	1.660	.140	4.335	5.215	2.768	2.301	1.496	2.164
1½	1.610	1.900	.145	5.061	5.969	2.371	2.01	2.038	2.835
2	2.067	2.375	.154	6.494	7.461	1.848	1.611	3.355	4.430
3	3.067	3.500	.217	9.636	10.996	1.245	1.091	7.388	9.621
3½	3.548	4.000	.226	11.146	12.566	1.077	.955	9.887	12.566
4	4.026	4.500	.237	12.648	14.137	.949	.849	12.730	15.904
4½	4.508	5.000	.246	14.153	15.708	.848	.765	15.939	19.635
5	5.045	5.563	.259	15.849	17.475	.757	.629	19.990	24.299
6	6.065	6.625	.280	19.054	20.813	.63	.577	28.889	34.471
7	7.023	7.625	.301	22.063	23.954	.544	.505	38.737	45.663
8	7.982	8.625	.322	25.076	27.096	.478	.444	50.039	58.426
9	9.000	9.688	.344	28.277	30.433	.425	.394	63.633	73.715
10	10.019	10.750	.366	31.475	33.772	.381	.355	78.838	90.762

Q. 525—How do you find the amount of steam which will flow through a given pipe in one minute with a given head or pressure?

A.—*Divide 3.6 by the diameter in inches; add one to the quotient, and multiply the sum by the length of the pipe in feet.* (PRODUCT I.)

Multiply the difference between the initial and terminal pressures by the fifth power of the diameter and by the density at the initial pressure. (*Product 2.*)

Divide Product 2 by Product 1, and multiply the square root of the quotient by 87.

$$W = 87 \sqrt{\frac{D\,(p_1 - p_2)\,d^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

where W = weight of steam discharged in pounds per minute.
D = density of steam at initial pressure.
p_1 = initial pressure.
p_2 = final pressure.
L = length of pipe in feet.
d = diameter of pipe in inches.

Table XVI gives the flow of steam in pounds per minute through 100 foot lengths of standard pipe-sizes with one pound loss of pressure. The flow is in each case calculated from the actual size of the pipe, as given in Table XV.

Q. 526—How would you find the flow through any other length of pipe, with one pound loss of pressure?

A.—*Divide the length through which the flow is required by 100. Find the square root of the quotient. Divide the tabular number by this square root. The result is the flow required.*

Q. 527—What is the flow per minute through 1600 feet of 7-inch pipe at 110 pounds initial pressure, with one pound loss of pressure?

A.—122.95 pounds, found as follows:

Tabular number = 491.81,
1600 ÷ 100 = 16.
$\sqrt{16} = 4$.
491.81 ÷ 4 = 122.9525.

Q. 528—How would you find the amount delivered with any other loss of pressure?

A.—*Multiply the amount given by the square root of the given loss.*

Q. 529—What would be the flow through 400 feet of 6-inch pipe with 9 pounds loss of pressure, initial pressure 10 pounds?

TABLE XVI.

WEIGHT IN POUNDS OF STEAM DELIVERED THROUGH 100-FOOT LENGTHS, WITH ONE POUND LOSS OF PRESSURE; FOR STANDARD PIPE SIZES AND VARIOUS INITIAL PRESSURES. FORMULA IS $W = 8.7\sqrt{\frac{D\ d^5}{d + 3.6}}$

Initial Press. by Gauge.	Nominal Inside Diameter of Pipe. See Table of Standard Sizes.														Initial Press. by Gauge.
	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	
1	.9414	2.0768	3.2243	6.5421	10.762	19.704	29.460	41.672	56.737	77.015	126.51	187.42	263.52	362.17	480.14	1
5	1.0466	2.3073	3.5821	7.2682	11.956	21.891	32.730	46.512	63.033	85.662	140 60	208.22	292.77	402.37	533.42	5
10	1.1612	2.5614	3.9767	8.0687	13.273	24.302	36.334	51.634	69.977	94.986	156.08	231.16	325.02	446.69	592.17	10
15	1.2652	2.7909	4.3319	8.7916	14.462	26.479	39.589	56.249	76.245	103.346	170.06	251.86	354.13	486.70	645.22	15
20	1.3605	3.0010	4.6591	9.4533	15.551	28.472	42.570	60.494	81.985	111.542	182.86	270.82	380.79	523.34	693.76	20
25	1.4483	3.1946	4.9597	10.0610	16.554	30.309	45.316	64.397	87.275	118.480	194.66	288.30	405.36	557.11	738.59	25
30	1.5305	3.3760	5.2412	10.6350	17.494	32.030	47.889	68.053	92.229	125.190	205.72	304.66	428.37	558.73	780.48	30
40	1.6819	3.7100	5.7598	11.6860	19.225	35.199	52.627	74.786	101.340	137.580	226.06	334.81	470.75	646.98	857.70	40
50	1.8179	4 0100	6.2256	12.6320	20.789	38.046	56.838	80.834	109.550	148.710	244.35	361.88	508.82	699.30	927.07	50
60	1.9443	4.2889	6.6585	13.5200	22.224	40.691	60.838	86.455	117.030	159.050	261.34	387.05	544.20	747.93	991.53	60
70	2.0625	4.5491	7.0626	14.3300	23.573	43.160	64.530	91.701	124.280	168.700	277.17	410.53	577.22	793.31	1051.70	70
80	2.1729	4.7930	7.4411	15.0980	24.833	45.473	67.989	96.617	130.940	177.740	292.06	432.54	608.17	835.84	1108.38	80
90	2 2769	5.0224	7.7974	15.8210	26.026	47.650	71.244	101.244	137.210	186.250	306.04	453.30	637.29	875.86	1161.30	90
100	2.3763	5.2417	8.1378	16.5120	27.162	49.731	74.354	105.663	143.200	194.380	319.77	473.03	665.11	914.09	1211.82	100
110	2.4706	5.4497	8.4606	17.1670	28.240	51.704	77.305	109.855	148.880	202.090	332.16	491.81	691.50	950.37	1259.90	110
120	2.5616	5.6505	8.7725	17.7990	29.280	53.610	80.154	113.903	154.350	209.540	344.32	509.93	716.98	985.39	1306.33	120
130	2.6494	5.8442	9.0731	18.4100	30.284	55.447	82.901	117 806	159.660	216.720	356.12	527.40	741.55	1019.59	1351.10	130
140	2.7333	6.0290	9.3603	18.9920	31.242	57.200	85.522	121.532	164.710	223.600	367.38	544.60	765.73	1052.90	1393.86	140
150	2.8143	6.2089	9.6378	19.5550	32.169	58.898	88.060	125.138	169.590	230.210	378.28	560.23	787.71	1082.59	1435.14	150

A.— $400 \div 100 = 4$.
$\sqrt{4} = 2$.
Tabular number = 156.08.
$156.08 \div 2 = 78.04$ = flow with 1 pound loss of pressure.
9 = given loss.
$\sqrt{9} = 3$.
$78.04 \times 3 = 234.12$.

Q. 530—What causes tend to reduce the flow?

A.—The friction of the steam as it enters the pipe, globe-valves and elbows.

Q. 531—How do you allow for these?

A.—The resistance at the opening and that at the globe-valve are both equal to that of a length of pipe equal to 114 diameters divided by a number represented by $12 \times (3.6 +$ diameter). This becomes

$$R = \frac{19\ d^2}{2\ (d + 3.6)}$$

where R = resistance in feet of pipe.
d = diameter in inches.

Table XVII gives the values of R for various numbers of various sizes of pipes.

The resistance of an elbow is $\frac{2}{3}$ times that of a globe-valve or an opening. Table XVIII gives values direct.

Q. 532—Example: A 6-inch pipe 200 feet long has one globe-valve and 7 elbows. What is the flow through it with 10 pounds initial pressure, and 1 pound loss of pressure?

A.—The resistance of the opening, being equal to that of a globe-valve, the sum of these resistances is equal to two valves. From Table XVII, opposite 6 inches and under 2, the resistance is found to be equal to that of 72.32 feet of pipe. The resistance of 7 elbows is found in Table XVIII, opposite 6 and under 7, to be equal to that of 168.77 feet of pipe. The total length of pipe is therefore taken at $200 + 72.32 + 168.77 = 441.09$ feet. The flow for 100 feet of length is 156.08 pounds per minute, and the flow for the given pipe is

$$156.08 \div \sqrt{\frac{441.09}{100}} = 74.3 \text{ pounds}$$

per minute.

TABLE XVII.

RESISTANCE OF GLOBE VALVES IN FEET OF PIPE. FORMULA, $R = \frac{19\ d^2}{2\ (d+3.6)}$

Nominal Inside Diameter	Number of Globe Valves.								
	1	2	3	4	5	6	7	8	9
1	2.24	4.49	6.74	9.08	11.23	13.47	15.72	17.94	20.21
1¼	3.62	7.25	10.87	14.50	18.12	21.74	25.37	28.99	32.62
1½	4.72	9.45	14.18	18.90	23.63	28.42	33.08	37.81	42.53
2	7.16	14.32	21.49	28.65	35.81	42.97	50.13	57.30	64.46
2½	9.54	19.08	28.62	38.16	47.70	57.24	66.78	76.52	85.86
3	13.40	26.80	40.20	53.60	67.00	80.40	93.80	107.20	120.60
3½	16.73	33.46	50.19	66.92	83.65	100.38	117.11	133.84	150.57
4	20.19	40.38	60.57	80.76	100.95	121.14	141.33	161.52	181.71
4½	23.81	47.62	71.43	95.24	119.05	142.86	166.67	190.48	214.29
5	27.97	55.94	83.91	111.88	139.85	167.82	195.79	223.76	251.73
6	36.16	72.32	108.48	144.64	180.80	216.96	253.12	289.28	325.44
7	44.11	88.22	132.33	176.44	220.55	264.66	308.77	352.88	396.99
8	52.26	104.52	156.78	208.04	261.30	313.56	365.82	418.08	470.34
9	61.07	122.14	183.21	244.28	305.35	366.42	427.49	488.56	549.63
10	70.02	140.04	210.06	280.08	350.10	420.12	490.14	560.16	630.18

TABLE XVIII.

RESISTANCE OF ELBOWS IN FEET OF PIPE. FORMULA, $R = \frac{19\ d^2}{3\ (d+3.6)}$

Nominal Inside Diameter of Pipe.	Number of Elbows.								
	1	2	3	4	5	6	7	8	9
1	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50
1¼	2.42	4.84	7.26	9.68	12.10	14.52	16.94	19.36	21.78
1½	3.15	6.30	9.45	12.60	15.75	18.90	22.05	25.20	28.35
2	4.74	9.48	14.22	18.96	23.70	28.44	33.18	37.92	42.66
2½	6.36	12.72	19.08	25.44	31.80	38.16	44.52	50.88	57.24
3	8.94	17.88	26.82	35.76	44.70	53.64	62.58	71,52	80.46
3½	11.16	22.32	33.48	44.64	55.80	66.96	78.12	89.28	100.44
4	13.46	26.92	40.38	53.84	67.30	80.96	94.22	107.68	121.14
4½	15.88	31.76	47.64	63.52	79.40	95.28	111.16	127.04	142.92
5	18.65	37.30	55.95	74.60	93.25	112.90	130.55	149.20	167.85
6	24.11	48.22	72.33	96.44	120.55	114.66	168.77	192.88	216.99
7	29.41	58.82	88.23	117.64	147.05	176.46	205.87	235.28	264.69
8	34.84	69.68	104.52	139.36	172.20	209.04	243.88	278.72	313.56
9	40.71	81.42	122.13	162.84	203.55	244.26	284.97	325.68	366.39
10	46.68	93.36	140.04	186.72	233.40	280.08	326.76	373.44	420.12

Q. 533—How would you compare two pipes of different size?

A.—By means of Table XIX. This shows the number of pipes of one size required to replace one pipe of another size under the same conditions.

TABLE XIX.

SHOWING THE RATIO BETWEEN THE DISCHARGES OF VARIOUS STANDARD PIPES. THE DISCHARGE VARIES AS $\sqrt{\frac{d^6}{d+3.6}}$

Inside Diam. of Pipe.	Inside Diameter of Pipe.														Nominal Inside Diam. of Pipe.
	1	1¼	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	
1		2.21	3.42	6.95	11.43	20.93	31.29	44.26	60.26	81.85	134.35	199.06	279.89	384.67	509.90	1
1¼			1.55	3.15	5.18	9.49	14 19	20.07	27.32	37.08	60.94	90.25	126.89	174.37	231.14	1¼
1½				2.03	3.34	6.11	9.14	12.92	17.60	23.89	39.25	58.13	81.73	112.37	149.19	1½
2					1.65	3.01	4.50	6.38	8.65	11.77	19.34	28.65	40.28	55.44	73.50	2
2½						1.83	2.74	3.87	5.27	7.16	11.76	17.42	24.49	33.65	44.65	2½
3							1.50	2.12	2.88	3.91	6.42	9.51	13.37	18.38	24.37	3
3½								1.42	1.92	2.61	4.30	6.36	8.95	12.29	16.30	3½
4									1.36	1.85	3.04	4.50	6.32	8.68	11.50	4
4½										1.36	2.23	3.30	4.59	6.38	8.48	4½
5											1.64	2.43	3.42	4.70	6.22	5
6												1.48	2.08	2.86	3.80	6
7													1.40	1.93	2.56	7
8														1.37	1.82	8
9															1.33	9

SECTION XI.

Horse-Power of Engines.

Q. 534—How are steam engines rated?

A.—By horse-power.

Q. 535—What is a horse power?

A.—33,000 foot-pounds per minute, 550 foot-pounds per second, or 1,980,000 foot-pounds per hour.

Q. 536—What is a foot-pound?

A.—One pound of force exerted through one foot of space.

Q. 537—How many foot-pounds of work are required to lift one pound one hundred feet?

A.—One hundred.

Q. 538—How many foot-pounds are required to lift 100 pounds one foot?

A.—One hundred.

Q. 539—How many foot-pounds are required to lift 110 pounds through 300 feet?

A.—$110 \times 300 = 33{,}000$ foot-pounds.

Q. 540—Would that be a horse-power?

A.—If it were done in a minute.

Q. 541—Suppose it were done in two minutes?

A.—Then there would be only $33{,}000 \div 2 = 16{,}500$ foot-pounds done *per minute*, which is only half a horse-power.

Q. 542—Is it correct to say "horse-power per minute," "horse-power per hour," etc?

A.—No. If an engine is doing work at the rate of 50 horse-power it is doing 50 horse-power all the time. It is an error which is frequently made to assume that such an engine is doing 50 horse-power per minute and 50 × 60 = 3,000 horse-power per hour. A little consideration of the above answers will show that such terms as those given in the question have no significance. When it is said, for instance, that an engine uses 20 pounds of steam per horse-power per hour it is meant that this amount of steam is used per hour for each horse-power developed.

Q. 543—One gallon of water weighs about 8 1-3 pounds. Disregarding friction, how many horse-power would be required to lift 10,000 gallons per hour to a height of 90 feet?

A.—8 1-3 × 10,000 × 90 = 7,500,000 foot-pounds per hour; 7,500,000 ÷ 60 = 125,000 foot-pounds per minute. One horse-power is 33,000 foot-pounds per minute; 125,000 foot-pounds per minute is 125,000 ÷ 33,000 = 3.8 horse-power.

Q. 544—How many foot-pounds of work would be required to drag 110 pounds on a level through 300 feet?

A.—Three hundred multiplied by the frictional resistance to motion, i. e., by the pounds of tension in the cord by which it is dragged. When the weight is lifted vertically the tension in the cord is equal to the weight itself; when the weight is supported the pull is determined by the friction of the weight on the surface. It is the pull on the cord, not the weight moved, which must be multiplied by the space moved through to get the foot-pounds of work consumed. The work done by a horse, for instance, is the pull on the traces multiplied by the distance through which the horse moves.

Q. 545—How do you find the foot-pounds of work done by a steam engine?

A.—Multiplied the average pressure per square inch during the stroke by the number of square inches in the piston and by the number of feet through which the piston has moved.

Q. 546—How do you find the horse power developed by a steam-engine?

A.—*Multiply the cross-sectional area of the cylinder in square inches by the mean effective pressure and by the piston speed, and divide by 33,000.*

Q. 547—How do you find the cross-sectional area of a cylinder?

A.—The same as that of any other circle; multiply the square of the diameter by .7854.

Q. 548—What do you understand by the "mean effective pressure?"

A.—The mean pressure is the average pressure pushing the piston through the stroke, but there is usually some back pressure working against it, and the effective pressure is only the difference between the two. The "mean effective pressure" is therefore the "average unbalanced pressure." It can only be determined accurately by measurement from an indicator diagram.

Q. 549—How do you find the piston speed?

A.—*On double acting engines multiply the stroke in inches by 2 and by the number of revolutions per minute and divide by 12.*

Q. 550—Why do you multiply by 2?

A.—Because there are in a double-acting engine two working strokes to each revolution. Steam-engines are generally double-acting, and so understood unless otherwise specified. If the stroke is given in feet or is easily reducible to feet, as in a 14 × 24 inch engine, you can multiply directly by the feet without dividing by 12 afterward.

Q. 551—Why do you divide by 12?

A.—To reduce the inches to feet.

Q. 552—What is a single-acting engine?

A.—An engine in which, like the Westinghouse, the steam acts on one side of the piston only.

Q. 553—How do you find the piston speed of a single-acting engine?

A.—*Multiply the stroke in inches by the revolutions per minute and divide by 12.*

Q. 554—What is the horse-power of a 12 by 24 inch engine running 125 revolutions per minute with 40 pounds mean effective pressure?

A.—Area $= 12 \times 12 \times .7854 = 113.0976$ sq. in.

Piston Speed $= 24 \times 2 \times 125 \div 12 = 500$ ft. per min.

M. E. P. $= 40$

Then

$$\frac{113.0976 \times 500 \times 40}{33.000} = 68.544 \text{ H. P.}$$

Q. 555—Give a handy rule for finding approximately the power of an engine from its diameter.

A.—*Take one-half of the square of the cylinder diameter.*

Q. 556—Figured by this rule, what would be the horse-power of the above engine?

A.—The square of the diameter is $12 \times 12 = 144$, and one-half of 144 is 72 horse-power.

Q. 557—Upon what conditions is it based?

A.—600 feet of piston speed and 35 pounds mean effective pressure, or 40 pounds mean effective pressure and about 525 feet of piston speed.

Q. 558—Of what use are such rules?

A.—Simply to be carried in the head as a quick and ready means of rough approximations. Simple engines are usually rated upon 40 pounds mean effective pressure. Piston speeds of 500 and 550 feet per minute are common, so that this rule will give the horse-power obtainable from a given cylinder under the conditions of average practice, but the limitations of such approximate rules should be understood, and they should not be applied to special cases.

SECTION XII.

The Slide-Valve.

Q. 559—What is the "cylinder" of an engine?

A.—The chamber in which the piston moves back and forth under the action of the steam.

Q. 560—What is the "steam-chest?"

A.—The chamber from which the steam is supplied to the cylinder.

Q. 561—What are the passages between the steam-chest and cylinder called?

A.—The steam-ports.

Q. 562—How is the supply of steam to and from the cylinder controlled?

A.—By the valve or valves.

Q. 563—What is a "single-valve" engine?

A.—An engine in which a single valve controls the admission and distribution of steam for both ends of the cylinder, as in a common slide-valve engine.

Q. 564—What is a "four-valve" engine?

A.—An engine having a separate steam and exhaust-valve for each end of the cylinder, as in a Corliss engine.

Q. 565—Describe a common D slide-valve, and its action.

A.—The valve-ports and cylinder are shown in section in Fig. 62. First, the piston is just starting to make a stroke, the valve having started open and admitted steam as shown at *a*. The steam contained in the other end of the cylinder is free to pass into the central exhaust passage *c*. Second, the valve has reached the end of its travel to the right and the port is wide

open or (in case the travel is not sufficient to open it fully) as much as it will be. The valve now travels to the left, and Third, has closed the steam-port and cut off the supply, the stroke being completed by the expansion of the steam already in the cylinder. Fourth, the exhaust-port has closed on one end and the inclosed steam will be compressed. A slight further movement will open the steam supply to the end which has been exhausting and open the other end to the exhaust, when the valve will be in the same position relative to the right-hand end that it was to the left-hand end at the beginning of the stroke.

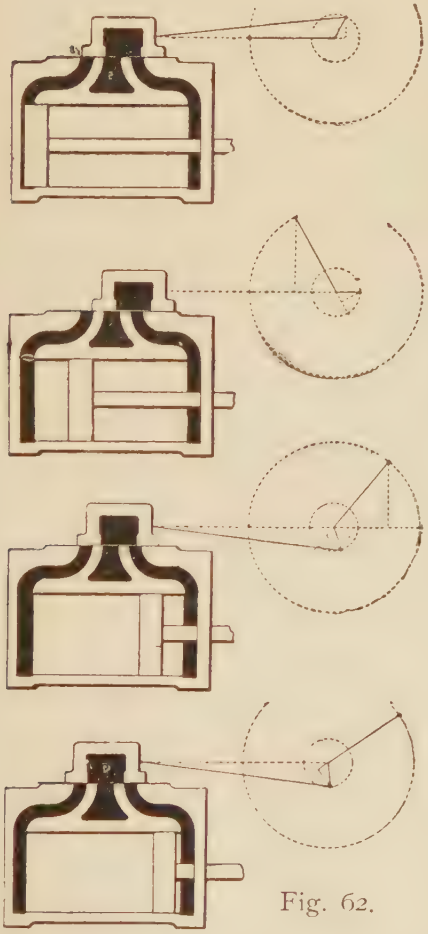


Fig. 62.

Q. 566—What is "lead?"

A.—The amount that a port is open when the piston is at the beginning of its stroke, as at *a*, Fig. 62.

Q. 567—What is "lap?"

A.—The amount that the blades of the valve project over the edges of the port when in its central position. See Fig. 63.

Q. 568—What is "inside lap?"

A.—The lap on the inside or exhaust-edge of the valve. See Fig. 63.

Q. 569—What is the effect of adding inside lap?

A.—Increasing compression and delaying release.

Q. 570—What is outside lap?

A.—The lap upon the outside or steam edge of the valve.

Q. 571—What is the effect of increasing the outside lap?

A.—For the same position of the eccentric it would make the admission later and the cut-off earlier. In order to keep the admission or lead the same we shall, after adding lap, have

to move the eccentric forward, which will make everything, cut-off, release, and compression, still earlier with reference to the stroke.

Q. 572—How do you find the area of the steam-port for a given size of cylinder?

A.—*Multiply the cross-sectional area of the cylinder in square inches by the piston speed, and divide by 6,000. The quotient will be the port-area required in square inches.*

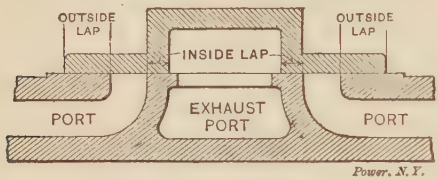


FIG. 63.

Q. 573—What is this rule based on?

A.—Allowing a velocity of 6,000 feet per minute to the entering steam.

Q. 574—How wide should the steam-port be?

A.—Wide enough to prevent "wire drawing," which is simply another way of saying "choking" or "throttling."

Q. 575—How long should the ports be?

A.—This depends upon circumstances. As nearly as possible, the length of the ports should be made equal to the diameter of the cylinder, a good rule being to make them .9 of the cylinder diameter.

Q. 576—Supposing the length of port to be .9 of the cylinder diameter, how would you find the width?

A.—By dividing the figure found in the answer to Q. 572 by .9 D, where D is the diameter of the cylinder. Table XX gives the widths of the ports in terms of the piston diameter for various piston speeds and velocities of steam flow.

Q. 577—How would you find the width of port for an engine 18 × 36, running at 100 revolutions per minute, assuming a velocity of 6,000 feet per minute for the entering steam?

A.—The piston speed is

$$\frac{36 \times 100 \times 2}{12} = 600 \text{ feet per minute.}$$

Under 6,000, column headed "Port Width," opposite 600, is .087. Multiplying 18, the cylinder diameter in inches, by .087 gives 18 × .087 = 1.566 inches as the proper width. This table assumes that the length of the port is .9 of the cylinder diameter.

Q. 578—What is the "lead-angle?"

TABLE XX.—Engine Ports.

Port Area, Port Width and Steam Pipe Diameter for Various Piston Speeds and Steam Velocities.

Piston Speed. Feet per Minute.	Velocity of Steam. Feet per Minute.														
	4,000.			6,000.			8,000.			10,000.			12,000.		
	Port Area. Piston Area as Unity.	Steam Pipe Diameter. Piston Diameter as Unity.	Port Width. Piston Diameter as Unity.	Port Area. Piston Area as Unity.	Steam Pipe Diameter. Piston Diameter as Unity.	Port Width. Piston Diameter as Unity.	Port Area. Piston Area as Unity.	Steam Pipe Diameter. Piston Diameter as Unity.	Port Width. Piston Diameter as Unity.	Port Area. Piston Area as Unity.	Steam Pipe Diameter. Piston Diameter as Unity.	Port Width. Piston Diameter as Unity.	Port Area. Piston Area as Unity.	Steam Pipe Diameter. Piston Diameter as Unity.	Port Width. Piston Diameter as Unity.
100	.025	.158	.022	.017	.129	.015	.013	.112	.011	.010	.100	.009	.008	.091	.007
125	.031	.177	.027	.021	.144	.018	.016	.125	.014	.013	.112	.011	.010	.102	.009
150	.037	.194	.032	.025	.158	.022	.019	.137	.017	.015	.123	.013	.013	.112	.011
175	.044	.209	.038	.029	.171	.025	.022	.148	.019	.018	.132	.015	.015	.121	.013
200	.050	.224	.043	.033	.183	.029	.025	.158	.022	.020	.141	.017	.017	.129	.015
225	.056	.237	.049	.038	.194	.033	.028	.168	.024	.023	.150	.020	.019	.137	.016
250	.063	.250	.055	.042	.204	.037	.031	.177	.027	.025	.158	.022	.021	.144	.018
275	.069	.262	.060	.046	.214	.040	.034	.185	.030	.028	.166	.024	.023	.151	.020
300	.075	.274	.065	.050	.224	.044	.038	.193	.033	.030	.173	.026	.025	.157	.022
325	.081	.285	.070	.054	.233	.047	.041	.201	.036	.033	.180	.028	.027	.164	.024
350	.088	.296	.076	.058	.242	.051	.044	.209	.038	.035	.187	.031	.029	.171	.025
375	.094	.306	.081	.063	.250	.055	.047	.217	.041	.038	.194	.033	.031	.177	.027
400	.100	.316	.086	.067	.258	.058	.050	.224	.044	.040	.200	.035	.033	.183	.029
425	.106	.326	.092	.071	.266	.062	.053	.231	.046	.043	.206	.037	.035	.188	.031
450	.113	.335	.098	.075	.274	.065	.056	.238	.049	.045	.212	.039	.038	.193	.033
475	.119	.344	.103	.079	.281	.069	.059	.244	.052	.048	.218	.041	.040	.199	.035
500	.125	.353	.108	.083	.288	.073	.063	.250	.055	.050	.224	.044	.042	.204	.036
525	.131	.362	.113	.088	.295	.076	.066	.256	.058	.053	.229	.046	.044	.209	.038
550	.138	.371	.119	.092	.302	.080	.069	.262	.060	.055	.235	.048	.046	.214	.040
575	.144	.380	.124	.096	.309	.084	.072	.268	.063	.058	.240	.050	.048	.219	.042
600	.150	.388	.130	.100	.316	.087	.075	.274	.065	.060	.245	.052	.050	.224	.044
625	.156	.395	.135	.104	.323	.091	.078	.279	.068	.063	.250	.055	.052	.228	.045
650	.163	.403	.141	.108	.329	.094	.081	.285	.071	.065	.255	.057	.054	.232	.047
675	.169	.411	.146	.113	.335	.098	.084	.290	.074	.068	.260	.059	.056	.237	.049
700	.175	.418	.150	.117	.341	.102	.088	.296	.077	.070	.265	.061	.058	.241	.051
725	.181	.426	.155	.121	.347	.106	.091	.301	.079	.073	.269	.063	.060	.246	.053
750	.188	.433	.161	.125	.353	.109	.094	.306	.082	.075	.274	.065	.063	.250	.055
775	.194	.440	.166	.129	.359	.113	.097	.311	.085	.078	.278	.068	.065	.254	.056
800	.200	.447	.172	.133	.365	.116	.100	.316	.087	.080	.283	.070	.067	.259	.058
825	.206	.454	.177	.137	.371	.120	.103	.321	.090	.083	.287	.072	.069	.262	.060
850	.213	.461	.183	.141	.376	.123	.106	.326	.093	.085	.292	.074	.071	.266	.062
875	.219	.468	.188	.145	.382	.127	.109	.331	.095	.088	.296	.076	.073	.270	.064
900	.225	.474	.193	.150	.388	.131	.113	.336	.098	.090	.300	.079	.075	.274	.065
925	.231	.481	.198	.154	.393	.134	.116	.340	.101	.093	.304	.081	.077	.277	.067
950	.238	.487	.204	.158	.398	.138	.119	.344	.104	.095	.308	.083	.079	.281	.069
975	.244	.494	.209	.162	.403	.141	.122	.349	.106	.098	.312	.085	.081	.285	.071
1000	.250	.500	.214	.166	.408	.145	.125	.353	.109	.100	.316	.087	.083	.289	.073
1025	.256	.506	.220	.170	.413	.149	.128	.357	.112	.103	.320	.089	.085	.292	.075
1050	.263	.512	.225	.175	.418	.153	.131	.361	.114	.105	.324	.092	.088	.295	.076
1075	.269	.518	.231	.179	.423	.156	.134	.365	.117	.108	.328	.094	.090	.299	.078
1100	.275	.524	.236	.183	.428	.160	.138	.370	.120	.110	.332	.096	.092	.303	.080
1125	.281	.530	.241	.187	.433	.163	.141	.375	.123	.113	.335	.098	.094	.306	.082
1150	.288	.536	.246	.191	.438	.167	.144	.379	.126	.115	.339	.100	.096	.310	.084
1175	.294	.542	.251	.195	.443	.170	.147	.384	.128	.118	.343	.103	.098	.313	.085
1200	.300	.548	.256	.200	.447	.175	.150	.388	.131	.120	.346	.105	.100	.316	.087

A.—The angle through which the eccentric is advanced to give the valve the proper lead.

Q. 579—How far is the crank from the center at the point of cut-off when the valve has both lap and lead?

A.—Two lap-angles and one lead-angle.

Q. 580—What is the "radius of eccentricity" of an eccentric?

A.—The distance between the center of the eccentric and the center of the shaft which carries it.

Q. 581—What is understood by the "throw" of an eccentric?

A.—Some writers use the word "throw" as meaning the radius of eccentricity, others as twice that radius. In the first case the "throw" of the eccentric would move the valve from its central position to the end of its travel in one direction; in the second case it would move it from one extreme of its stroke to the other. The first use is the more general.

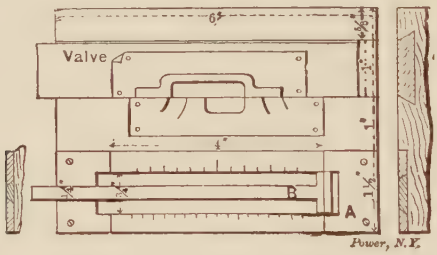


FIG. 64.

Q. 582—How wide should the bridges be?

A.—The thickness of the bridges is determined by the character of the casting, and is usually about the same as the cylinder-walls. They may conveniently be figured about $\frac{3}{8}$ths of an inch thicker than one-half the width of the port.

Q. 583—How can the action of a slide-valve best be studied?

A.—By means of a model.

Q. 584—Describe the construction of a model suitable for this purpose.

A.—Cut out a strip of brass like *A*, Fig. 64, to represent the cylinder. It should be about 6 inches long by $1\frac{1}{2}$ inches wide and the slot should be $4\frac{1}{2}$ by $\frac{3}{4}$ of an inch. The piston may be represented by a T-shaped piece of brass of the same thickness, held in position under the larger plate by beveling off the edges of both cylinder-head and rod, as shown in the section. The piston has a stroke of four inches, which may be divided

into common fractions upon one side and decimals upon the other as shown, a line being drawn across the piston to mark its position with reference to the divisions. This trip is screwed to a block of wood 6 inches long, 4 inches wide, and $2\frac{3}{4}$ inches thick. One-half inch from the further edge a dove-tailed slot is cut, one inch in width at the top, leaving an inch of the surface of the block between the edge of the slot and the brass plate. A piece of soft wood is fitted to slide nicely in this slot to represent the valve.

An adjustable eccentric is made as shown in Fig. 65. The eccentric proper is $2\frac{1}{2}$ inches in diameter over the flanges and $\frac{3}{8}$ of an inch thick. The flanges are $\frac{1}{16}$ wide and high, making the bearing for the eccentric strap $2\frac{3}{8}$ inches in diameter by $\frac{1}{4}$ inch wide. Through the center is a $\frac{3}{8}$ inch slot $1\frac{1}{4}$ inches in length, and on one side of the disk a slot $\frac{1}{2}$-inch wide and $\frac{1}{16}$ deep is cut clear across, as shown in the drawings. Into this slot is fitted a block, shown at the right, the body of the block passing through the $\frac{3}{8}$-inch slot, the flange fitting into the half-inch groove. It should be tapped to receive the screw *D*. Now out of $\frac{3}{8}$-inch stock make the piece shown at the left, boring a clean hole for the screw *D*, which taps into the block as explained above, also a $\frac{5}{16}$ inch hole for the main shaft, and put in a set-screw *E* for fastening this piece and the shaft together. Have the fit upon the shaft easy but not loose. The shaft is $\frac{5}{16}$ of an inch in diameter and 3 inches long. Mount the eccentric on the shaft as shown in Fig. 66. Its position on the shaft can be fixed by a set-screw at *E*, and the valve can be given any amount of movement up to $1\frac{1}{2}$ inches, by moving the disk across the shaft, securing it in the desired position by the screw *D*, the greatest eccentricity being $\frac{3}{4}$ of an inch. You can make a scale for the amount of throw by setting the eccentric first so that it will run true and making a mark upon the eccentric and upon the stationary piece. Then mark a scale of 16ths on the face of the eccentric toward the center. You can then set the eccentric by this scale to give any amount of movement to the valve without other measurement. A simple form of eccentric strap is shown in Fig. 67, and a flat strip of brass bent as shown in Fig. 68 will serve as the eccentric rod. It must be connected to the valve

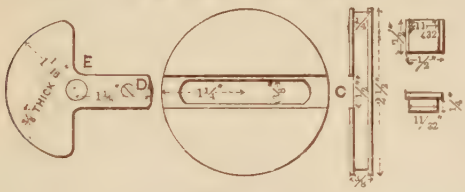


FIG. 65.

stem with a clamp-screw, so as to be adjustable. The crank should be cut out of $\frac{3}{8}$-inch metal, and be 2 inches from center to center. A piece of wire bent at right angles and set into the base and the block, as in Fig. 68, makes a simple main-guide. The connecting rod should be about 10 inches in length. It remains now simply to add a disk about five inches in diameter, of thin metal, divided into degrees at its edges, or into 10ths of an inch on one side and 8ths on the other. The zero line should be in the same plane as the crank pin center, so that the indicator will stand at zero when the piston is at the end of the stroke.

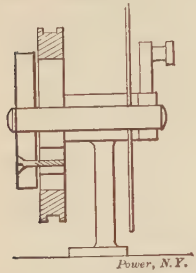


FIG. 66.

Q. 585.—How is this model used?

A.—Lay the valve and ports out to scale, as in Fig. 63. If the actual valve has over $1\frac{1}{2}$ inches movement, which is the limit of the model, use such a scale as will bring the movement within this limit. With a valve having a $2\frac{1}{2}$-inch movement for instance, the valve and ports should be drawn one-half the actual size. Pin the drawing of the valve on the soft wood sliding block, and that of the ports on the space between the valve and the cylinder, as in Fig. 64. Next set the eccentric at a point which will give the necessary throw. This with the $2\frac{1}{2}$ inch actual movement given above would require the eccentric to be set $\frac{5}{8}$ out of center, giving the $1\frac{1}{4}$ inch of movement necessary on the half scale. Now place the model on the center and adjust the eccentric so as to give the proper lead, and by turning the shaft around you can see what the action of the valve will be with reference to the piston. You can also see what the effect of changes in the lap, travel, width of port, and bridges would be, much more clearly than by any diagram or drawing.

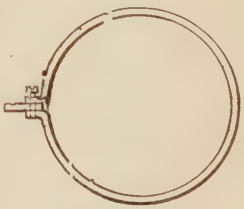


FIG. 67.

Q. 586.—What do you understand by the "lap-angle?"

A.—The angle through which the crank moves in moving the valve a distance equal to the outside lap.

Q. 587.—When a valve has outside lap, through what angle will it move while steam is being admitted?

A.—Through 180 degrees, less twice the lap-angle.

Q. 588.—Where, then, would the crank stand at cut-off if the valve opens when the engine is on the center?

A.—Two lap-angles away from the center.

Q. 589—What is the angular advance of an eccentric?
A.—The amount it is set ahead of a line at right angles with the crank. The lap-angle plus the lead-angle.

Q. 590—What is the least width for an exhaust-port to give constant opening at least equal to the steam-port?
A.—The radius of eccentricity plus one-half of the width of the steam-port plus the exhaust-lap minus 3-8ths of an inch.

Q. 591—What other means are there for determining the action of slide-valves?
A.—Valve diagrams.

Q. 592—Give a prominent example of these.
A.—That designed by Dr. Gustav Zeuner.

Q. 593—How is it constructed?
A.—Draw the lines *AO* and *CO*, Fig. 69, crossing each

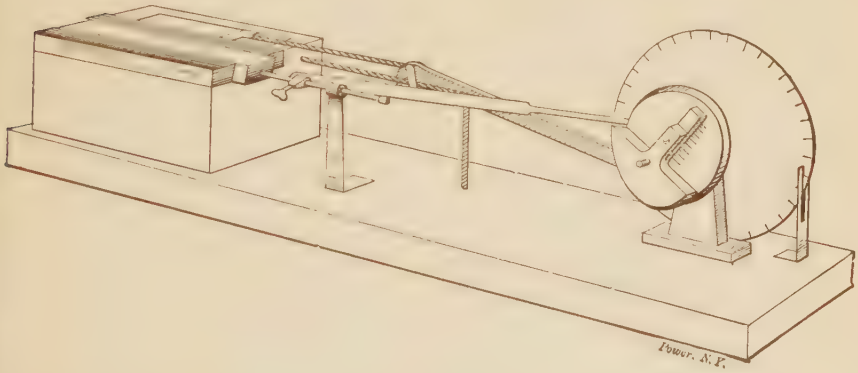


FIG. 68.

other at right angles, and *OE* in such a position that the angle *AOE* is equal to the angle of advance, i. e., to the number of degrees in excess of 90 or a right angle that the eccentric leads the crank. Make *OE* equal to the radius of eccentricity, and on it draw a circle, called the valve-circle. Now suppose the crank to be turning about the center *O*, and the line *CO* to be in the line of centers of the engine, then that portion of a line which represents the crank in any position which lies within the valve-circle will be a measure of the amount which the valve has moved from its central position. For instance, when the crank-pin is in the position *1* the line *O1* is just ready to cut into the valve-circle, and the valve is just passing its central position

and commencing its movement toward the end of the cylinder under examination. When the crank gets to the position *C* the valve will have moved a distance equal to *Oc*. The extreme movement away from its central position is reached when the crank is at *E*, the movement at this point being *OE*, which it will be remembered was the radius of eccentricity. It can readily be seen that the eccentric is just passing the center when the crank is in this position, for the eccentric is the angle *AOE* plus a right angle ahead of the crank, which would bring the eccentric on the left hand center with the crank at *E*. After this the valve begins to move back toward its central position, slowly at first, having moved backward only a distance equal to *Aa* while the crank was going from *E* to *A*, *aO* representing its distance from the center for this position, *Of* when the crank is at *f*, etc., until when the crank gets in line with *1O* again the circle no longer cuts it, and the valve is again in the central positon.

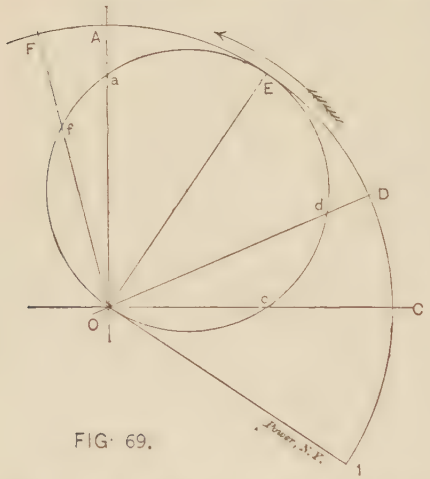


FIG. 69.

Q. 594.—These lines give the total *movement* of the valve. How do you determine the amount of steam-port opening?

A.—To do this we must subtract from the total movement of the valve, as indicated in Fig. 69, the outside lap. This can be done graphically by striking an arc with *O* for a center and with a radius equal to the lap in question. In Fig. 70 this arc with the radius *O L* has been put in. As before, when the crank is in the position *O1* the valve is in its central position. When the crank has got to *B* the movement *Ob* of the valve has been just equal to the width of the lap and the port will now commence to uncover. Admission therefore takes place with the crank at *B*, and when the crank gets on the center *C* the port will be open an amount equal to *Lc*, which is the lead. The position of the crank when the lap cuts off the steam may be determined by drawing a line from *O* through the point of intersection *g* of the valve and lap circles. If the above explanation has been followed it will readily be seen that the valve has

moved backward, when the crank is in this position, an amount $Gg = Ee$, equal to the total travel less the lap, and that the lap must now cross the edge of the port in order that the rest of the half-revolution may bring the valve to its central position. If the valve travels just to the edge of the port the distance on the crank lines between the lap and valve circles, as *Lc*, *Ee*, *Hh*, etc., will give the amount of port opening for the relative positions.

Q. 595.—What is overtravel?

A.—Overtravel occurs when the valve not only opens the port fully but travels by. The overtravel is the amount which the outside edge of the valve passes by the inside edge of the port, as at the left in Fig. 78.

Q. 596.—When this occurs, how can it be represented in the Zeuner diagram?

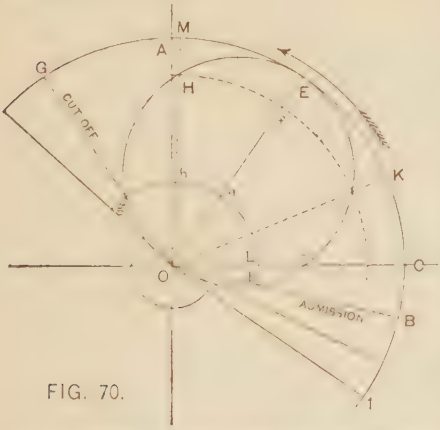


FIG. 70.

A.—On the diameter *OE*, Fig. 70, of the valve-circle lay off a space *ef* outside of the lap-circle equal to the width of the port, and with *O* as a center draw the arc of a circle through *f* as indicated by the dotted arc. Then it will be seen that when the crank gets to *K* the port will be wide open and remain so until the crank gets to *M*, the edge of the valve having in the meantime traveled past the edge of the port a distance equal to *fE* and back again.

Q. 597.—Can you tell anything about the compression and release by means of this diagram?

A.—Yes; the compression and release depend upon the inside lap, but they occur when the valve is on the opposite side of the central position from that at which admission and cut-off take place. Look at the valve in Fig. 71. In order to admit steam to the right-hand end of the cylinder it must move to the left. Cut-off will occur as it is coming back, but while it is still to the left of the central position. Now, that release may occur in the right-hand end of the cylinder, the valve must move to the *right* of its central position an amount equal to the inside

lap, *ab*. In order to determine the position of the crank at this point we must put in the valve-circle for the opposite or right-hand movement. In Fig. 79 this has been done. We can now trace the relative positions of the valve and crank throughout the revolution. When the crank is in the position marked 1, its center-line cutting neither circle, the valve will be in the central position, as shown in Fig. 71. When in the position marked 2, its center-line cutting the intersection of the valve and lap-circles, it will have moved to the left the distance *OL*, the amount of the outside lap, and admission will begin as in Fig. 72. When the crank gets to the center, 3, the valve will be open the amount of the line *O*3, included between the valve and lap-circles and marked "steam-lead" on the diagram, in the position shown in Fig. 73. When it gets to position 4, where its center line passes though the intersection of the valve-circle and the dotted arc bounding the width of the port, the port will be fully open, as in Fig. 74. When the crank gets to 5, its center-line coinciding with the diameter of the valve-circle,

FIG. 71.

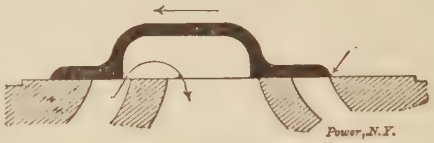


FIG. 72.

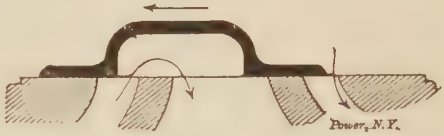


FIG. 73.

FIG. 74.

FIG. 75.

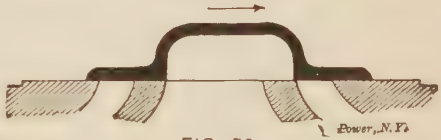


FIG. 76.

FIG. 77.

FIG. 78.

the valve will be in its extreme left-hand position, as in Fig. 75. At 6 it has come back over the overtravel and is again in the position shown in Fig. 74. The port now commences to close, and at 7, where the center-line of the crank cuts again the intersection of the valve- and lap-circles, the valve closes and cut-off takes place, the valve being in the position shown in Fig. 72. At 8, where the center-line passes again between the valve-circles

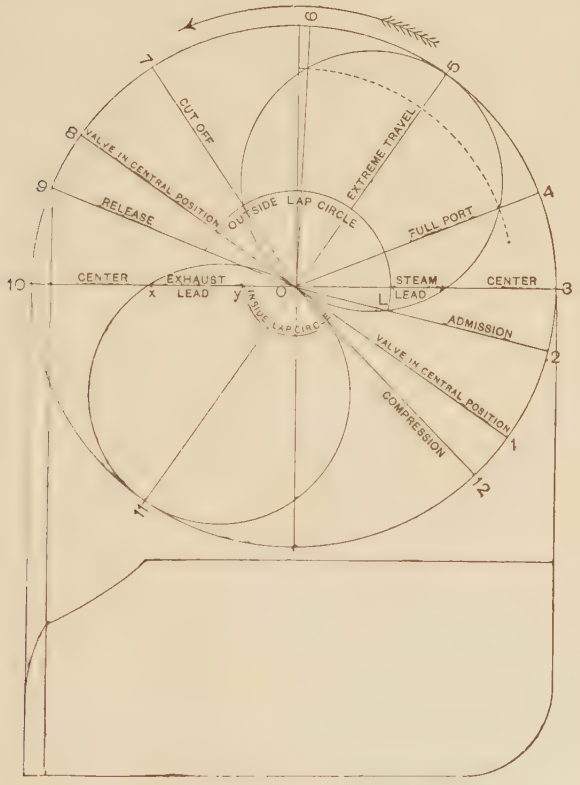


FIG. 79.

without cutting either, the valve is again in the position shown in Fig. 71. The center-line of the crank now passes into the other valve-circle, and when it cuts the intersection of that circle with the inside lap-circle, struck from the center *O* with a radius equal to the inside lap, the valve will be in the position shown in Fig. 76, and release will take place, the crank being at 9, Fig. 79. When the crank passes the opposite center at 10 the valve has moved to the right a distance equal to *Ox*, and

the portion *Oy* of this movement having been required to move the lap, the exhaust port will be open an amount equal to *xy*, and the valve will be in the position shown in Fig. 77. When the crank gets to 11 the valve will be in its extreme right-hand position, as shown in Fig. 78, and when it gets to 12, where its center-line again passes through the intersection of the inside lap and valve-circles the valve will again be in the position shown in Fig. 76, but moving toward the left, and compression

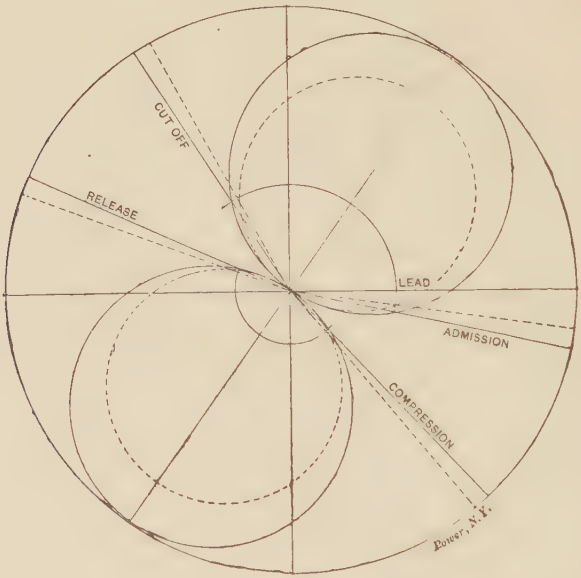


FIG. 80.

will commence. By referring the points indicated to a line representing the stroke it can be seen what kind of an indicator diagram an engine with this valve should make.

Q. 598.—Show by the Zeuner diagram what would be the effect of decreasing the travel.

A.—In Fig. 80 the full lines represent the diagrams as it has been drawn in the previous figures. Suppose now the radius of eccentricity or throw of the valve is decreased from the diameter of the full line valve-circle to that of the dotted circle. Drawing the dotted lines through the intersection of the dotted circles and the lap-circles as shown, we find the admission will be later, the lead less, the cut-off earlier, the release later, and the compression earlier.

Q. 599—What is the effect of decreasing the angle of advance, i. e., setting the eccentric back toward the crank?

A.—In Fig. 81 the full lines represent the valve as it has been drawn, the dotted lines with the eccentric set back. The effect is to make all the events later with reference to the stroke of the piston. The valve opens later, giving less lead, cut-off and release are later, and the exhaust-port closes later, giving less compression.

Q. 600—What is the effect of setting the eccentric ahead?

A.—To make all the events earlier with reference to the stroke. Admission is earlier, giving more lead, cut-off and

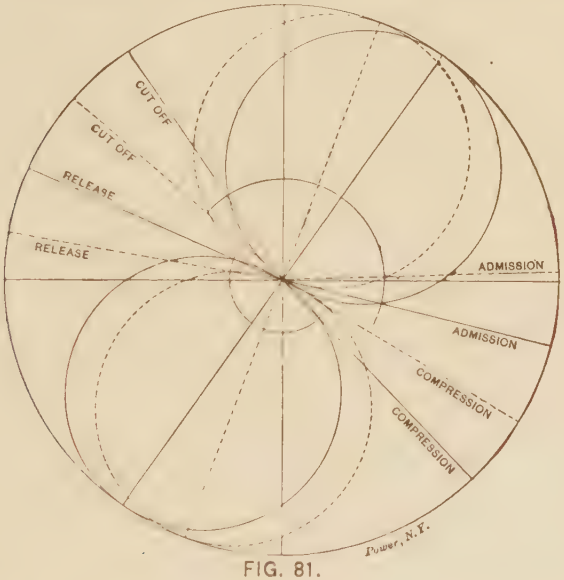


FIG. 81.

release are earlier, and the exhaust-valve closes earlier, giving more compression.

Q. 601—What is the effect of adding outside lap?

A.—In Fig. 82 the full lines represent the valve as originally drawn, the dotted lines with an increase of outside lap, The effect is to make the admission later and the cut-off earlier. The lead is of course diminished. If the eccentric is set ahead enough to give the same lead with the greater lap we shall have a still earlier cut-off, earlier release and compression, and an admission as early as it was before.

Q. 602—How would you set the valve of a slide-valve engine?

A.—I would first put the engine on the center.

Q. 603—What do you mean by putting an engine on the center?

A.—Placing it so that the wrist-pin, crank-pin, and center of the main shaft are in line, as in Fig. 85.

Q. 604—Describe a method of doing this accurately.

A.—Turn the engine until the cross-head is about half an inch from the end of its stroke, and mark the position of the cross-head as at *a* Fig. 83. Place a marker against the edge

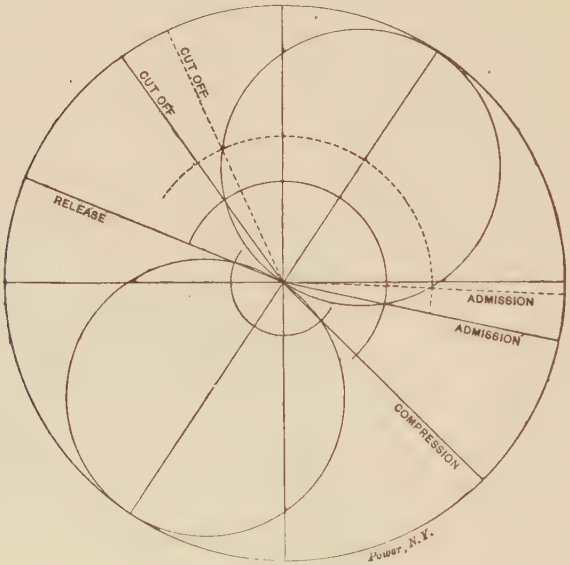


FIG. 82.

of the fly-wheel and make a mark upon the fly-wheel opposite the pointer, as at *b*. Turn the engine until the cross-head completes the stroke and comes back until the mark *a* is in line again. The crank will now be as much below the center as it was above before, as shown in Fig. 84. In this new position make another mark upon the fly-wheel opposite the pointer, as shown at *c*. Midway between the points *b* and *c* make a mark *e*. Turn the engine until the mark *e* is opposite the pointer and the engine will be on the center, as in Fig. 85.

In all the operations of putting the engine on the center care must be taken that the engine is always turned in the direction in which it is to be run, because in that way the lost motion, back-lash or play of the reciprocating parts will

make itself felt in precisely the same way as under running conditions, and therefore the valve, when set, will act as it is designed. For example, if in turning the engine to get the mark *a* on the cross-head in line with the mark *a* on the guides, the cross-head should happen to run by a little way, it will be necessary to turn the engine around a complete revolution to bring the marks in line. Of course, it would be much easier to simply reverse the direction of movement and thus bring the marks in line with a comparatively small movement; but a very serious error might be introduced thereby, because after the reversal the lost motion or play of the moving parts would permit of a very considerable movement of the fly-wheel before any movement of the cross-head would occur, and as a result the fly-wheel would move considerably back of its true position before the marks would line up. This would increase the distance between the two extreme marks on the fly-wheel, and consequently the middle point would not indicate the dead center. That is to say, if this mistake of reversing the motion of the fly-wheel is made, it will be found that when the pointer is opposite the central mark on the rim, the crank will be decidedly above or below its true dead center position.

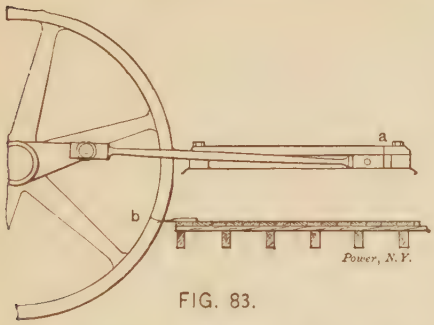


FIG. 83.

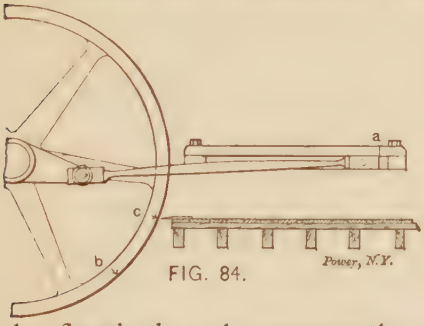


FIG. 84.

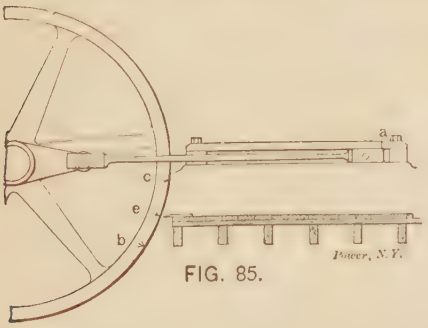


FIG. 85.

Q. 605—What is the next step?

A.—Place the eccentric crank in the direction the engine is to run, as in Fig. 86 if the engine is to run over, Fig.

87 if it is to run under. Then set it carefully at such a point that the valve will have just commenced to open on the end that should be taking steam.

Q. 606.—What would be the effect of a rocker-arm between the eccentric rod and valve stem?

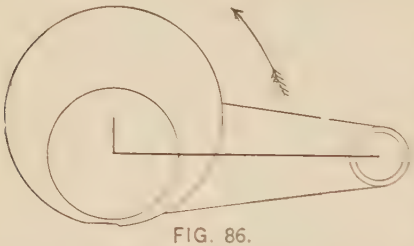


FIG. 86.

A.—If there is a rocker-arm which reverses the direction of motion, i. e., which makes the valve-stem move in the opposite direction from the eccentric-rod, the eccentric must be set behind the crank, as in Fig. 88, when the engine is to run "over" in order that the port may open as the engine turns forward; but if a rocker-arm like that in Fig. 89 is used, merely to multiply the motion without changing its direction, proceed as though there were no rocker-arm at all.

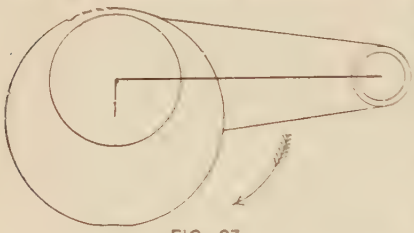


FIG. 87.

Q. 607.—What is the next step?

A.—Measure the lead which you have given to the end which you have set. This is most easily done by pushing a wedge-shaped piece of soft wood into the port opening as in Fig. 90. The edges of the valve and port will mark the distance it goes in. Turn the engine upon the other center and see if the lead is the same. If it is, the engine is properly set.

FIG. 88.

Q. 608.—What do you do if the lead is different on the two ends?

FIG 68.

A.—Move the valve on the stem toward the end having the greatest lead a distance equal to one-half the difference in the leads. If the equalized lead is more than is necessary, set the eccentric back a little. There are numerous methods of attaching the stem to the valve. A common way is shown in Fig.

91. With this arrangement it is necessary only to turn back the nuts on the end toward which the valve is to be moved an amount which will allow of the given movement, and then turn the others up until the valve is forced against the other nuts. When the stem screws directly into the valve the connection to the rocker-arm or guide must be undone, and the stem screwed into or out of the valve enough to give it the required position.

Q. 609—Into what two classes are engines divided with reference to the manner in which they are governed?

A.—Throttling, and automatic cut-off.

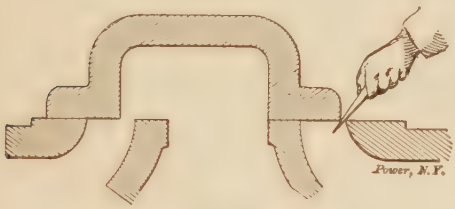


FIG. 90.

Q. 610—What is a throttle governed engine?

A.—An engine in which the amount of steam supplied is regulated by changing the pressure at which it enters the cylinder, in accordance with the load.

Q. 611—What is an automatic cut-off engine?

A.—An engine in which the amount of steam supplied is regulated by cutting off the supply automatically at various points in the stroke in accordance with the load and pressure. In the throttling engine the volume admitted is constant, the pressure varied. In the automatic cut-off steam is admitted at the highest available pressure, and the volume is varied to meet the requirements of the load.

Q. 612—Into what two classes may the automatic engines be divided?

A.—The single-valve type, in which the point of cut-off is varied by changing the amount of travel of the valve, and the four-valve engines in which the cut-off is usually effected by a detaching mechanism or trip under the control of the governor.

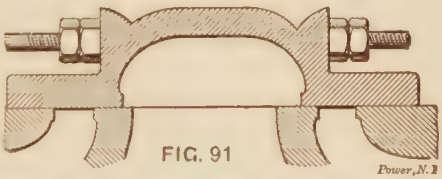


FIG. 91

Q. 613—Give examples of the single-valve type.

A.—Most of the high-speed self-contained engines with shaft-governors.

Q. 614—What are their advantages?

A.—High rotative speed, light weight, compactness, portability, and simplicity.

Q. 615.—How does their economy compare with that of the four-valve engines?

A.—The four-valve engines are the more economical.

Q. 616.—What cross or intermediate type is there?

A.—Four-valve engines the steam valves of which are operated directly from shaft governors without detachable connections, the object being to attain the economy of the four-valve type, with the positiveness, simplicity, and high rotative speed of the directly operated valve mechanism.

Q. 617.—Give examples of this type.

A.—Payne, Atlas, Von Mengeringhausen, Ball & Wood.

SECTION XIII.

The Corliss Engine.

Q. 618—Give a prominent example of the four-valve detaching cut-off type.

A.—The Corliss.

Q. 619—Describe the valve arrangement of a Corliss engine.

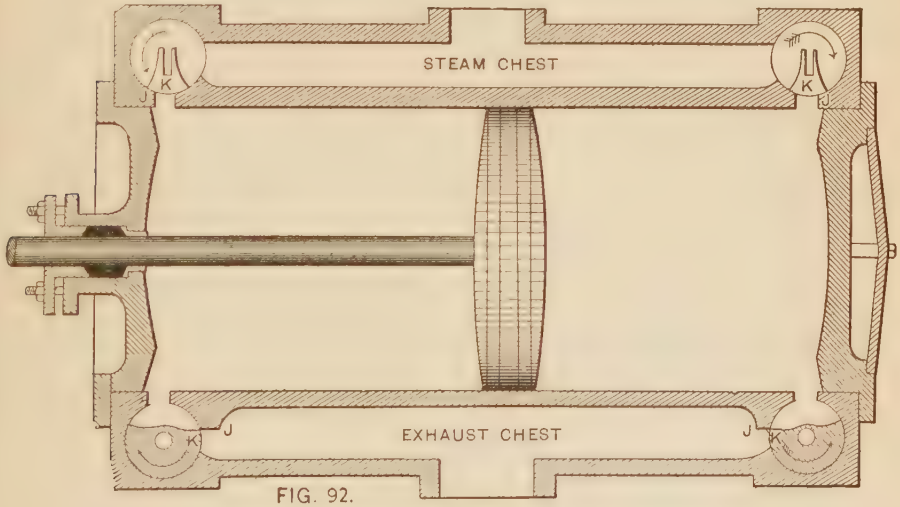


FIG. 92.

A.—The cylinder and valves are shown in section in Fig. 92. The steam-valves are shown in section at the top of the cylinder, the exhaust-valves at the bottom. The steam-valve is also shown in perspective in Fig. 93. These valves are semi-rotary, working on a semi-circular seat.

Q. 620—How do they get their motion?

A.—From a wrist-plate on the side of the cylinder (see Fig. 95).

Q. 621—How does this wrist-plate get its motion?

A.—From an eccentric on the main shaft, usually through a rocker-arm, as shown in Fig. 95.

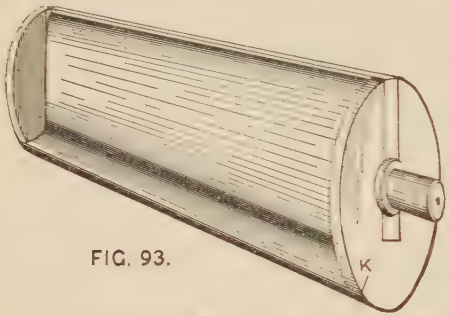


FIG. 93.

Q. 622—How are the valves turned by the wrist-plate?

A.—A crank upon the end of each valve-stem is connected to the wrist-plate by a small connecting-rod.

Q. 623—Are these connections positive?

A.—Those of the exhaust-valves are, so that the motion of those valves, both in opening and closing, is derived entirely from the wrist-plate. The crank on the steam-valve-stems is detachably connected with the wrist-plate by a releasing mechanism under the control of the governor.

Q. 624—How is the steam-valve closed after the mechanism is released?

A.—By means of a vacuum dash-pot connected to another crank arm on the valve stem (see Fig. 95).

Q. 625—Name and describe a typical example of one of these releasing mechanisms.

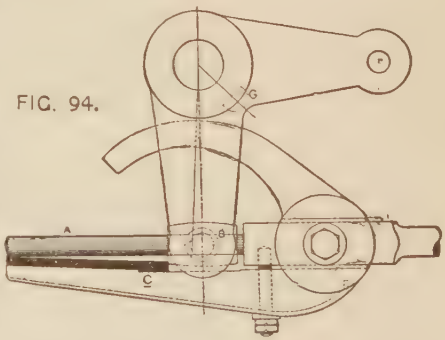


FIG. 94.

A.—The crab-claw was for a time quite generally used. It is shown in Fig. 94. The rod *A*, which is a prolongation of the rod leading from the wrist-plate, passes through the block *B*, which is attached to one arm of a bell-crank upon the valve-stem, the other end being attached to the dash-pot rod. The lower arm of the claw is held upward by a spring and carries a steel block, *C*, which engages with the block *B*. When the wrist-plate moves to the right, carrying the crab-claw with it,

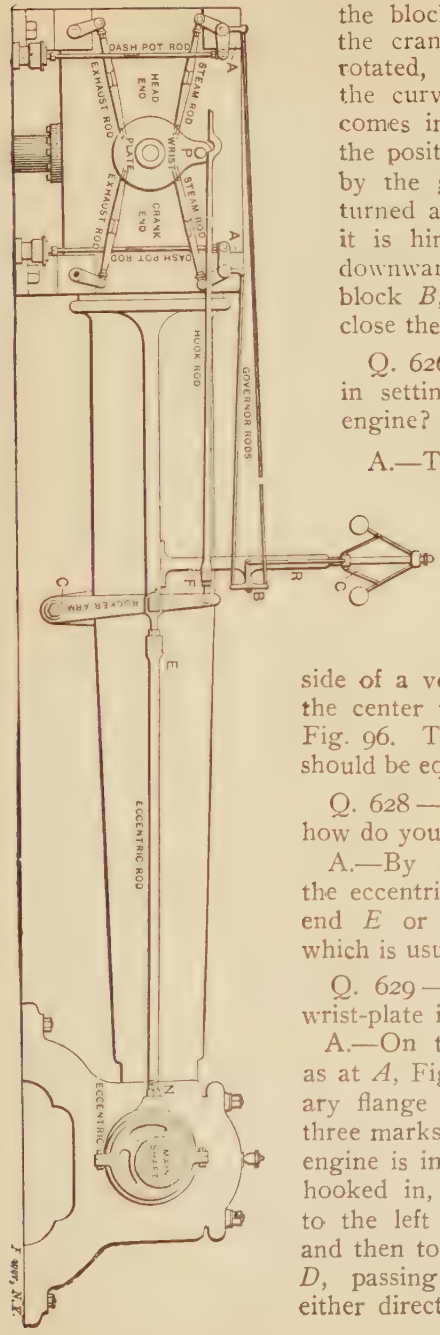


FIG. 95.

the block *B* is carried along, and the crank to which it is attached rotated, opening the valve. When the curved face of the upper arm comes in contact with the boss *G*, the position of which is determined by the governor, the crab-claw is turned around the bolt upon which it is hinged, forcing the block *C* downward out of contact with the block *B*, allowing the dash-pot to close the valve.

Q. 626.—What is the first step in setting the valves of a Corliss engine?

A.—To see that the motion is properly transmitted to the wrist-plate.

Q. 627.—How is this assured?

A.—See first that the rocker-arm vibrates to equal distances on each side of a vertical line passing through the center upon which it turns, as in Fig. 96. The distances *A D* and *B D* should be equal.

Q. 628.—If this motion is not equal, how do you correct it?

A.—By lengthening or shortening the eccentric-rod by means of the stub end *E* or the equivalent adjustment which is usually provided.

Q. 629.—How do you know if the wrist-plate is traveling correctly?

A.—On top of the wrist-plate hub, as at *A*, Fig. 97, and upon the stationary flange against which it runs, are three marks, as *B*, *C* and *D*. When the engine is in motion and the wrist-plate hooked in, the mark *A* should travel to the left until it is in line with *C*, and then to the right until in line with *D*, passing beyond these marks in either direction.

Q. 630—How do you correct it if it does not do so?

A.—By changing the length of the hook-rod by means of the adjustment at *F*, Fig. 95, until the plate travels to its marks.

Q. 631—Suppose the hook-rod is provided with no adjustment?

A.—Then adjust the eccentric-rod to bring the plate to its marks, without reference to the travel of the rocker-arm.

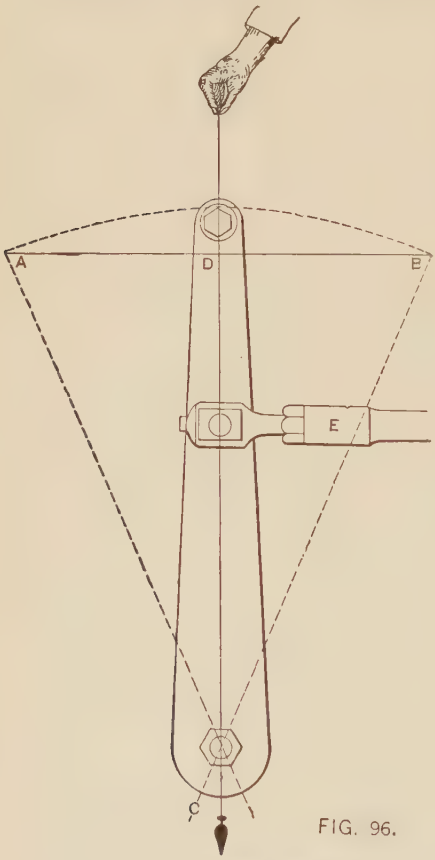


FIG. 96.

Q. 632—What do you do when there is no stub-end adjustment on the eccentric-rod?

A.—Detach the connection of the rod to the rocker-arm, slack the nut *N*, Fig. 95, and turn the rod into or out of the strap to get the proper length.

Q. 633—What is the next step?

A.—Remove the back bonnets from both the steam and exhaust-valves.

Q. 634—What will be found beneath the bonnets?

A.—The circular end of the valve will be seen, as in Fig. 98, and should have a mark *K* corresponding with the opening edge, as shown in Fig. 93. There should also be a mark *J* on the face of the valve-chamber corresponding with the edge of the port.

Q. 635—What is the purpose of these marks?

A.—To show the position of the working edge of the valve with reference to the port, and allow the lap and lead to be measured.

Q. 636—How should this lap and lead be adjusted?

A.—Place the wrist-plate upon the central mark, i. e., in the position shown in Fig. 97. Then adjust the length of the steam and exhaust-rods to give the steam-valves from $\frac{1}{4}$ to $\frac{9}{16}$ of

an inch of lap, and the exhaust-valves from $\frac{1}{32}$ to $\frac{3}{16}$ opening. All Corliss engines are not alike in their valve proportions, but Table XXI will answer the requirements of general practice.

Q. 637.—On which side of the port mark *J* should the valve mark *K* be to indicate lap?

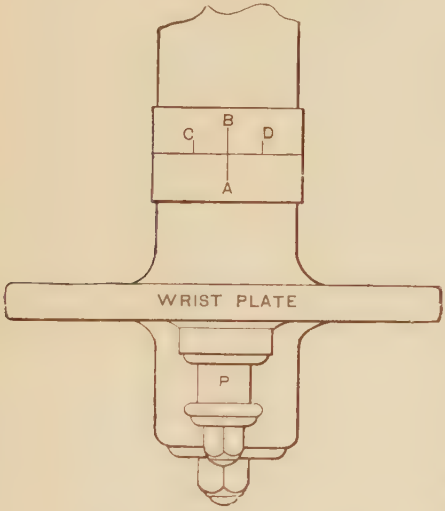


FIG. 97.

A.—This depends upon whether the valve opens inward or outward. When the valve opens inward the steam has to go over the top of the valve, and around to the port. This would be the case with the arrangement shown in Fig. 95; the crank on the valve-stem being below the center, the steam-valves open as they are turning toward the wrist-plate. To avoid this indirect path, some engines are built to open as the valve is turning away from the wrist-plate, as would be the case if the cranks on the valve-stems in Fig. 95 extended upward. See whether the port is to the right or left of the mark *J*, or by moving the wrist-plate or studying the motion, find in which direction your valves move to open the port, then set with the lap and lead given when the wrist-plate is in its central position.

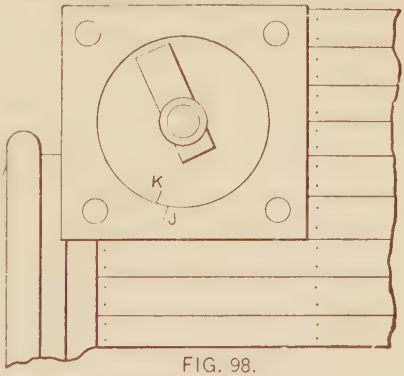


FIG. 98.

Q. 638.—Having set the valves evenly with the wrist-plate in the central position, how would you proceed?

A.—Place the engine on the center, at either end, hook in the rod, and set the eccentric just enough ahead of the crank in the direction in which the engine is to run to give the steam valves the proper amount of lead. Then turn the engine over

until it is on the other center. If the work has been done exactly the lead will be the same on this end as on the first. The probabilities are, however, that it will not be exactly the same, but the difference should be but slight, and can be corrected by making a small change in the proper steam connection. This will, of course, throw the lap out slightly, but not enough to make any material difference in the running of the engine.

It is well to note that while there is a great difference between the operations in setting a Corliss valve and those in setting a D-valve, the principles are the same. There are, on a D-valve, four factors that affect the distribution of steam; the two steam-

TABLE XXI.

Size of Engine.	Steam-Valve Lap.	Exhaust-Valve. Opening.
12	1/4	1/32
14	5/16	1/32
16	5/16	1/32
18	3/8	1/16
20	3/8	1/16
22	3/8	1/16
24	7/16	3/32
26	7/16	3/32
28	7/16	3/32
30	1/2	1/8
32	1/2	1/8
34	1/2	1/8
36	1/2	1/8
38	9/16	3/16
40	9/16	3/16
42	9/16	3/16

laps and the two exhaust-laps. So there are in the Corliss engine, or, in fact, any four-valve engine, four factors which affect the distribution of steam; the two steam-laps and the two exhaust-laps. In setting a Corliss valve the same thing is done as in setting a D-valve, with the addition that the proper lap is given in four places.

Q. 639—Will it not sometimes happen that under the most advantageous arrangement of the lap the steam-valve when it holds on for the full stroke will remain open after the exhaust valve on the same end has opened?

A.—Yes, but as in ordinary practice an engine rarely runs without the steam-valves tripping, this condtion may be tolerated to secure a better distribution under working conditions when the steam-valves will be closed by the dash-pot comparatively early in the stroke.

Q. 640—What are the disadvantages of excessive lap on the steam-valves?

A.—It reduces the rapidity and amount of movement of the valve at the point of opening, and diminishes the range through which the engine will cut off.

Q. 641—Explain how it reduces the rapidity of opening.

A.—It is well understood that a reciprocating motion derived from a crank is intermittent. An engine piston, for instance, starting from a state of rest at the end of its stroke, gradually increases in speed up to about the center and gradually comes to rest at the other extremity, the fastest travel being when the crank is at a right angle to the line in which the motion is transmitted, that is, to the guides. Now an eccentric is simply a crank, and will transmit its fastest motion to the wrist-plate when at a right angle to the horizontal, as shown in Fig. 99.

But the point at which this fastest motion is desired is when the crank is in the horizontal position; that is, when the engine is on the center and the stroke is about to commence, and in order to attain this object, the eccentric would have to be set at a right angle with the crank. With this arrangement, when the crank has moved through 45 degrees, or one-eighth of a revolution, and has reached the position shown by the dotted lines, the eccentric will also have assumed the position indicated by the dotted eccentric, and a movement proportional to the distance *a b* would have been communicated to the wrist-plate. Let the line *AB*, twice the length of the crank, represent the stroke of the piston, and for the position of the crank shown the piston would have advanced only to *C*. From this it will be seen that the movement of the piston through one-eighth of its stroke has moved the wrist-plate through nearly three-quarters of its throw to the right, while for the next equal movement of the crank, that is, to the vertical position, the wrist-plate will be moved only an amount equal to *bc*. Another point to be observed is that the eccentric, and hence the

wrist-plate, continues to move to the right until the crank is vertical, that is, until one-half the stroke has been completed. Inasmuch as the tripping of the valve in most of the detaching gears must be done while the wrist-plate is on its outward movement, this arrangement would allow the cut-off to take place at any point up to one-half stroke.

But the eccentric can only be set at right angles to the crank when there is no lap, and the greater the lap the more the eccentric must be set ahead to give the steam-valve the proper lead.

If, now, the eccentric instead of being at a right angle to the crank, as in Fig. 99, is set 30 degrees ahead of that position, as in Fig. 100, the movement of the crank through one-eighth of a revolution will produce a movement of the eccentric and wrist-plate proportional to *de*, Fig. 100, very considerably less than that shown with the former arrangement. The total movement of the wrist-plate in the direction of opening the valves after the stroke commenced would be *dcf* instead of *abc*, giving a much smaller movement to the valve.

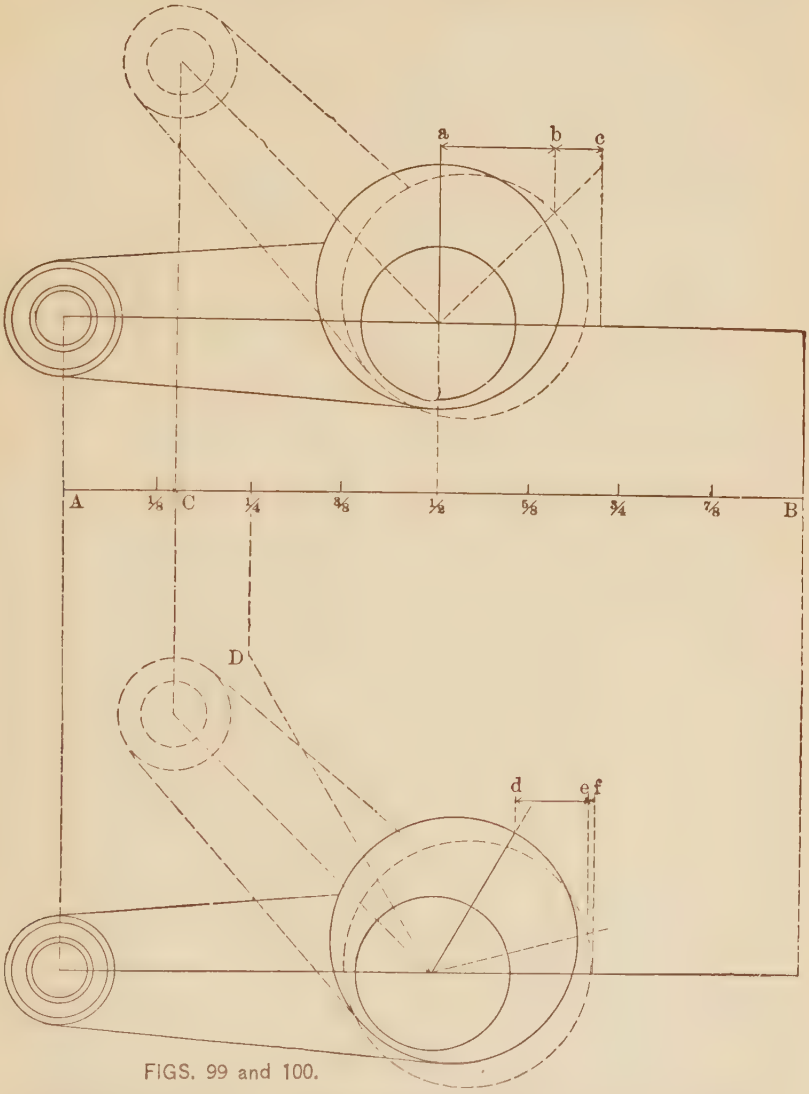
Q. 642.—How does it limit the range through which the engine can cut off?

A.—In most of the detachable cut-off mechanisms the valve can be tripped only while the wrist-plate is traveling away from its central position. If cut off does not occur before the wrist-plate reaches the extreme of its travel and starts back it cannot take place at all, and the engine will carry steam full stroke. The wrist-plate reaches the extreme of its travel when the eccentric gets to the line of centers. If the eccentric is set at right angles with the crank, as in Fig. 99, it can turn a quarter of a revolution or until the crank is vertical before the wrist-plate motion is reversed. If it is set more than a right angle ahead of the crank it has a proportionally smaller distance to travel before reaching the center, and less of the stroke will be made when it gets there. But if we give the valves more lap we must give the eccentric more advance in order to get a prompt admission.

Q. 643.—Can an engine with such a detachable cut-off possibly cut off beyond half stroke?

A.—Yes, possibly. It cannot cut off after the crank is at right angles to the guides, because the eccentric must be at least 90 degrees ahead of the crank; but on account of the angularity of the connecting-rod the piston is not in the center of the stroke when the crank is in the center of its half revolution.

This is shown in Figs. 101 and 102, where it will be seen that when the cross-head is in the middle of its stroke at *b* the crank is at *B*, to one side of its upright position; and when it

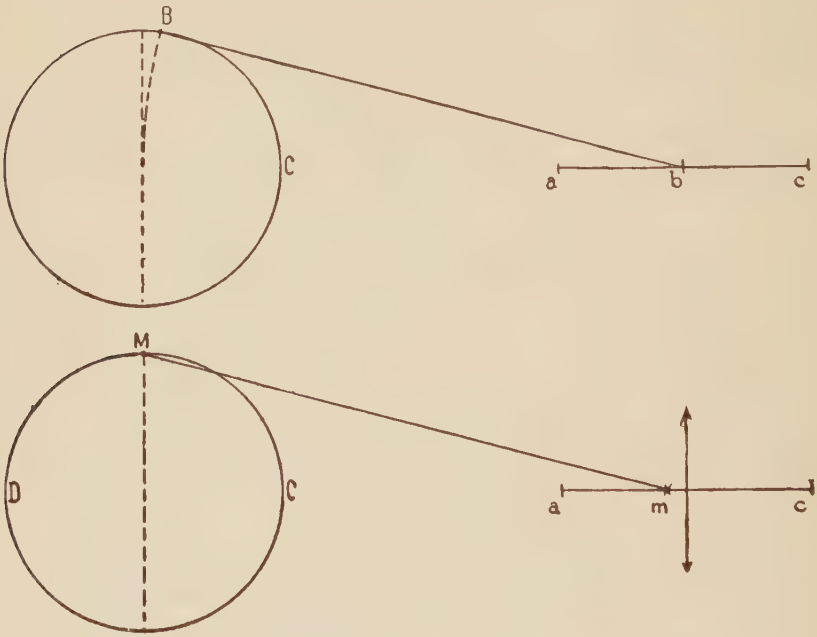


FIGS. 99 and 100.

reaches its upright position *M* the cross-head is at *m*, beyond the center of the stroke. The cut-off could occur on the head end up to *m* if the eccentric were square with the crank.

Q. 644.—With these disadvantages pertaining to excessive lap, why not cut the lap down to that required to close the valve?

A.—An answer to this proposition may be found in the exhaust-valves. If you set both exhaust-valves so that they will be line-and-line with the edge of the port when the engine commences its stroke, the valve at the end where the piston is will be just closing, and the valve at the end which is to be ex-



FIGS. 101 and 102.

hausted will be just opening, when the piston commences its movement. But the valve on the exhausting end should be opened before the piston arrives at the end of its stroke in order to secure a proper release, and the valve on the admission end should be closed before the piston is at the end of its stroke in order to give a proper degree of compression. If we turn the working edge of the valve away from the edge of the port by lengthening the exhaust-rod, so as to give it lead in opening, we shall make it later in getting back to close; and if, on the other hand, we lap the valve more, making it close earlier and giving the proper compression, it will open later and make a late release. When with the exhaust-rods we give an engine

more compression we make the release later; and conversely, when we quicken the release we take off compression, and the only way to make both the opening and the closing earlier is to make the whole motion of the valve earlier with reference to that of the piston by moving the eccentric ahead. When we have set the eccentric ahead, unless we have already considerable lap upon the steam valves, we shall have too much steam lead, and must set the valve back by lengthening the steam-valve rod and giving it more lap.

Q. 645 —How may this difficulty be overcome?

A.—By putting on an independent wrist-plate and eccentric for the exhaust valves.

Q. 646 —What can be done when the engine has but one eccentric?

A.—Divide up the release and compression to suit the engine upon which you are at work. Some engines require more compression than others. Then set the eccentric so as to give the required amount of each, and then set the steam valve back with the rod until it has only the necessary amount of lead. If you find this requires too much angular advance to the eccentric, you will have to sacrifice something on the exhaust valve.

Q. 647 —What now remains to be done?

A.—To adjust the governor so that the valves will cut off equally on both ends.

Q. 648 —How is this done?

A.—Put the wrist-plate in one of its extreme positions, having the mark *A* in line with *C* or *D* (Fig. 97) and adjust the length of the governor-rod which controls the valve that is opened by the movement of the wrist-plate to this point, so that the boss which operates the detaching mechanism is about one thirty-second of an inch out of contact. Throw the wrist-plate to its other extreme and adjust the length of the opposite governor rod. To test the accuracy of the operation, block the governor up to its normal running position, turn the engine over slowly, and measure the distance of the cross-head from the beginning of its stroke when the cut-off occurs. Continue turning the engine and notice the point at which the cut-off occurs on the opposite end. If there is any material difference, equalize the distance by lengthening one rod and shortening the other. Another method is to adjust the rods so that both ends will commence to cut off at the same revolution when starting up.

SECTION XIV.

Engines in General.

Q. 649—What is a "right-hand" engine?

A.—An engine the fly-wheel of which is to the right, as looked at from the cylinder. See Fig. 103.

Q. 650—What is a "left-hand" engine?

A.—An engine the fly-wheel of which is to the left as looked at from the cylinder. See Fig. 104.

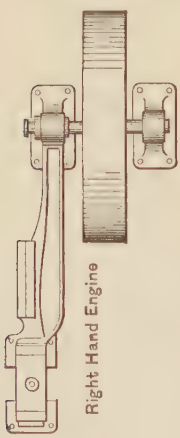


Fig. 103.

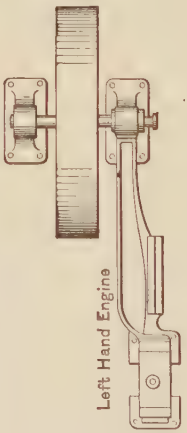


Fig. 104.

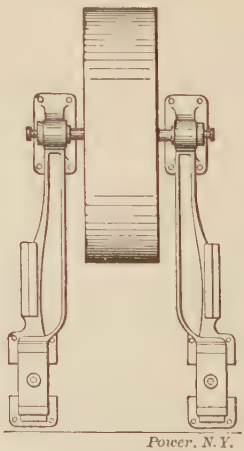


Fig. 105.

Q. 651—In that case, when the engine is a double or pair, does not the right-hand engine come on the left hand side?

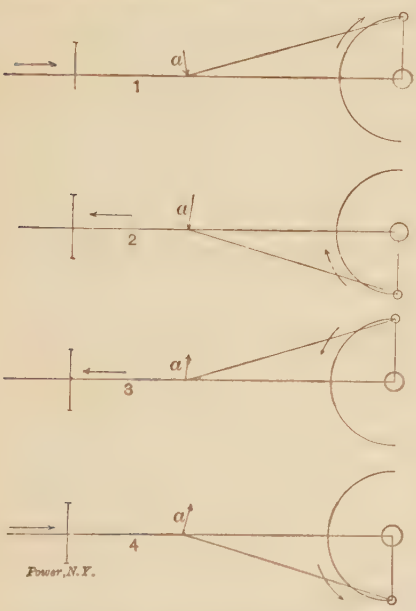
A.—No; the cylinders become respectively the right and left hand cylinders of the double engine. See Fig. 105.

Q. 652—What is meant by an engine running "over?"
A.—The top of the wheel running away from the cylinder. See Fig. 106.

Q. 653—What is meant by an engine running "under?"
A.—The top of the wheel running toward the cylinder. See Fig. 108.

Q. 654—Which way are engines more generally run?
A.—Over.

Q. 655—What advantages pertain to running an engine in this way?
A.—The pressure of the cross-head is always downward upon the guide, for when the pressure is on the head end of the piston the thrust against the connecting-rod which is pointing upward, as in Fig. 106, reacts to press the cross-head down upon the guides; and when the pressure is on the crank end of the cylinder, as in Fig. 107, the cross-head will be dragging the crank and as the crank is below the center line, it will still pull the cross-head down upon the lower guide. If on the other hand the engine is run "under," the thrust of the cross-head will be upon the top guide on both the outward and inward strokes, as shown in Figs. 108 and 109, and unless the cross-head is nicely adjusted to its guides, and the guides are perfectly parallel under running conditions, the cross-head will be lifted when subjected to thrust, and fall by its own weight on the centers, making the engine pound.



FIGS. 106, 107, 108 AND 109.

Q. 656—When is it desirable to have an engine run under?
A.—When it is impossible so to locate the engine as to give the proper direction to the belt from an "over" running wheel. For example, it is often desirable in electric work, on account of lack of room, to belt backward to the dynamo, giving the

necessary distance between shaft centers with the least space between the machines. But it is also desirable that the tight side of the belt shall be on the bottom. This can only be accomplished by running the engine under. See Fig. 110.

Q. 657 —Is it more desirable to do this than to run the engine "over" and draw from the top of the belt?

A.—It is. It is by no means impossible to make an engine run quietly when turning under. It simply requires truth in its construction, and care in its adjustment.

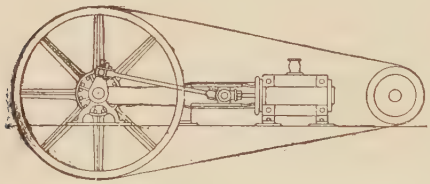


FIG. 110.

Q. 658 —Are there compensating advantages to running an engine under?

A.—There is a reduction of pressure on the guides, for when the engine runs over, the lower guide has to bear the weight of the cross-head and a part of the connecting-rod plus the stress due to the diagonal thrust; while when the engine runs under, the thrust on the upper guide is opposed by the weight of the cross-head and rod, and the pressure on the bearing surface will be the difference instead of the sum of these quantities.

Q. 659 —How can you determine the pressure on the guides for a given position of the cross-head?

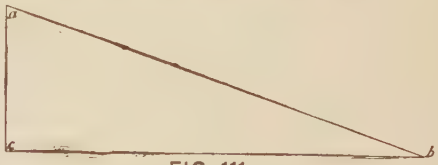


FIG. 111.

A.—Draw a line, as *a b*, Fig. 111, at the same angle from the horizontal line *bc* that the connecting-rod bears to the guides. Complete the triangle by drawing a line *ac* at right angles to the horizontal. As the length of the line *ac* is to the length of the line *bc*, so is the perpendicular thrust of the cross-head on the guide to the parallel thrust of the piston on the cross-head.

Q. 660 —At what point in the stroke is the thrust on the cross-head greatest, for a uniform pressure in the cylinder?

A.—When the crank is at right angles to the guide.

Q. 661 —What would be the thrust due to the steam pressure in a 30 by 60 inch engine having a connecting-rod five times as long as the crank, when the crank was at right angles to the guides, if there was an unbalanced pressure of 50 pounds per square inch in the acting end of the cylinder?

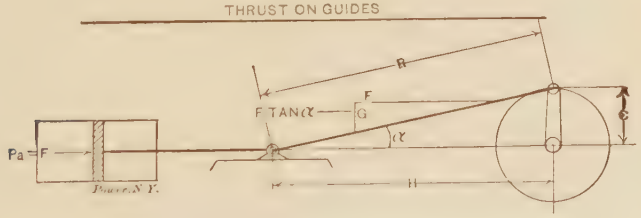
A.—The area of the piston is $30^2 \times .7854 = 706.86$ square inches, and at 50 pounds per square inch the horizontal thrust on the piston would be $706.86 \times 50 = 35{,}343$ pounds. The downward thrust would be to the horizontal thrust as *ac*, Fig. 111, is to *cb* when *ac* is one-fifth of *ab*, and the downward thrust may be determined by laying the triangle out to scale, having *ab* five times *ac*, dividing the horizontal thrust by the length of *bc*, and multiplying by *ac;* or since the base of a right angled triangle is the square root of the difference between the square of the other two sides, we can assume $ac = 1$, $ab = 5$, then $b = \sqrt{5^2 - 1^2} = \sqrt{24} = 4.898$, and the *thrust on the guides would be* $\frac{1}{4.899}$*th of the horizontal thrust, or* $35.343 \div 4.899 = 7.214$ *pounds, over* $3\frac{1}{2}$ *tons, from which we get the following:*

RULE:—TO FIND THE MAXIMUM PRESSURE ON THE GUIDES DUE TO THE STEAM PRESSURE.

Multiply the area of the piston in square inches by the pressure per square inch when the crank is at right angles with the guides. The product will be the horizontal push on the cross-head at this point.

Divide the length of the connecting-rod by the length of the crank, and subtract 1 from the square of the quotient.

Divide the horizontal thrust found as above by the square root of the remainder. The quotient will be the maximum thrust at right angles to the guides, due to the steam pressure.



P = pressure in pounds per square inch;
a = piston area in square inches;
F = horizontal force $= P \times a$;
G = pressure on guides $= F \tan \alpha$;

Tang. $\alpha = C \div H$, but since $H = \sqrt{R^2 - C^2}$

$$\text{Tan. } \alpha = \frac{C}{\sqrt{R^2 - C^2}} \text{ and}$$

$$\text{Pressure on guides} = \frac{Pa\ C}{\sqrt{R^2 - C^2}}$$

We can evidently make C = unity and tabulate values of $\sqrt{R^2 - C^2}$

for various proportions of crank length to rod length, when formula (1) becomes,

$$G = \frac{Pa}{K}, \text{ in which } K = \text{constant.}$$

VALUES OF $K = \sqrt{R^2 - C^2}$, WHEN $C = 1$.

R	3.	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
K	2.83	2.94	3.04	3.15	3.25	3.36	3.46	3.56	3.67	3.77	3.88	3.98	4.08	4.18	4.29	4.39	4.49	4.6	4.7

R	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0
K	4.8	4.9	5.0	5.1	5.2	5.31	5.41	5.51	5.61	5.71	5.82	5.92

Q. 662—How does the relative length of the connecting-rod affect this pressure?

A.—The longer the connecting-rod as compared with the crank, the less will be the pressure on the guides.

Q. 663—What is the usual ratio of connecting-rod to crank?

A.—The rod is from four to five times the length of the crank.

Q. 664—What are the objections to a long rod?

A.—A long connecting-rod makes a long engine and involves extra cost in the bed or frame, the room occupied, etc. The longer rod is heavier, and brings extra weight on the cross-head and crank-pins, guides, etc., and a long rod lacks stiffness, unless excessively heavy.

Q. 665—What determines the length of the crank?

A.—The stroke.

Q. 666—What limits the stroke?

A.—The piston speed limits the length of stroke allowable with a given rotative speed, or the number of revolutions per minute with a given stroke.

Q. 667—What limits the piston speed?

A.—The mechanical and practical difficulties of handling matter in motion at too great a velocity.

Q. 668—What is the practical limit to piston speed?

A.—Engines of four to six feet stroke can run at from 700 to 800 feet. Shorter strokes should not run over 600.

Q. 669—Why do high speed engines have a short stroke as compared with their diameter?

A.—Because they can run at a high rotative speed without exceeding the limit of piston speed.

Q. 670—What disadvantages pertains to the short stroke?

A.—The clearance bears a proportionately larger percentage to the volume of the piston displacement.

Q. 671—What is the office of the fly-wheel?

A.—To maintain a substantial uniformity of motion of the crank, notwithstanding the unequal moving force upon the crank-pin.

Q. 672—Is this force unequal even when the pressure in the cylinder is uniform throughout the stroke?

A.—Yes. Whatever the pressure on the piston, it has no effect in the direction of turning the engine when the crank is in line with the guides. Every engineer who has got his engine "on the center" knows this. As the crank gets away from the line of centers the effect of a given pressure becomes greater, reaching its maximum when the crank is nearly at right angles with the guides, and growing less as the crank approaches the other center.

Q. 673—How does the fly-wheel counteract the jerky motion of the crank which would result from this?

A.—By its inertia it resists an acceleration of motion when the effective moving force is excessive, and by its momentum keeps the engine in motion when the moving force is deficient.

Q. 674—How do you find the weight required in a fly-wheel?

A.—Requirements and conditions differ so materially that it is difficult to give a general rule. Different kinds of work will admit of more or less variation. Some kinds of machinery serve the purpose of a fly-wheel in themselves, so that the wheel upon the engine which drives them may be proportionately lighter.

Professor Thurston gives the formula—

$$W = \frac{a\,A\,S}{N^2\,D^2}$$

in which—

a = A constant ranging from 10,000,000 to 15,000,000 according to the character of the work, and averaging in ordinary practice about 12,000,000;

A = area of piston in sq. in.;
S = stroke of piston in feet;
D = diameter of wheel in feet;
N = revolutions per minute;
W = required weight of the rim in pounds.

Q. 675—Express this formula as a rule.

A.—*Multiply the area of the piston in square inches by the stroke in feet and by 12,000,000 for average work. Divide this product by the square of the number of revolutions per minute multiplied by the square of the diameter of the wheel in feet. The quotient will be the required weight of the rim of the wheel in pounds.*

SECTION XV.

Pulleys, Belting and Shafting.

Q. 676.—What is the relation between speeds and diameters of driving and driven pulleys?

A.—If there is no slippage the speeds will be inversely as the diameters of the pulleys. If the driven pulley is one-half the diameter of the driver its shaft will make twice the number of revolutions of the driving shaft. If the driven is twice the size of the driver its shaft will make one-half the number of revolutions of the driver, and so on for any other proportion.

Let D = diameter of driving pulley,
d = " " driven "
R = rev. per min. driving shaft,
r = " " driven "

then $$D : d :: r : R$$

from which proportion any of the factors can be found by the rule of three.

Q. 677.—How do you find the size of driven pulley required with a given driver to produce a given number of revolutions of the driven shaft?

A.—To find the size of driven pulley from the above proportion:

$$\frac{D\,R}{r} = d.$$

Multiply the diameter of the driving pulley by the number of revolutions it makes per minute and divide by the speed of the

driven shaft. The quotient will be the diameter of driven pulley required.

EXAMPLE:—An engine having a 12-foot fly-wheel is run at 95 revolutions per minute. What size pulley must be used on the jack-shaft in order that it may run 120 revolutions per minute?

$$\frac{12 \times 95}{120} = 9.5 \text{ feet.}$$

It is frequently more convenient to use the diameter of the pulleys in inches. It makes no difference in the calculation, but the diameters of *both* pulleys must be taken in the same units of measurements. If one is given in inches reduce the other to inches.

Q. 678—How would you find the size of driving pulley required to give a required speed to a driven shaft?

A.—TO FIND THE SIZE OF DRIVING PULLEY REQUIRED.

$$\frac{d\ r}{R} = D.$$

Multiply the diameter and speed of the driven together and divide by the speed of the driver. The quotient will be the diameter of the driver.

EXAMPLE:—On a shaft which is to run 320 revolutions per minute there is a 3-foot pulley. The driving shaft runs 180 revolutions per minute. What must be the diameter of the driving pulley?

$$\frac{dr}{R} = \frac{36 \times 320}{180} = 64 \text{ inches.}$$

Q. 679—How would you FIND THE SPEED OF ONE SHAFT, diameter of pulleys and speed of the other shaft being given?

$$\frac{D\ R}{d} = r \text{ or } \frac{dr}{D} = R$$

Multiply the diameter of the pulley whose speed is given by the speed, and divide by the diameter of the other pulley.

EXAMPLE:—A pulley 28 inches in diameter and running at 280 revolutions per minute is belted to a 34-inch pulley on another shaft. How fast will the latter shaft run?

$$\frac{D\ R}{d} = \frac{28 \times 280}{34} = 230. + \text{ revs. per min.}$$

Q. 680—Suppose you have a driving shaft which runs 110 revolutions and a driven shaft which must run 165. How would you know what size pulleys to use?

A.—The pulleys must be to each other inversely as the speeds.

$$\frac{R}{r} = \frac{d}{D} \text{ or } \frac{110}{165} = \frac{2}{3}$$

The pulleys must be to each other as 2 is to 3, i. e., the driven must be $\frac{2}{3}$ the diameter of the driver. We can fulfill this condition by making the driven pulley 6 inches and the driver 9; or by making the driver 30 feet and the driven 20. The size of the pulleys will then have to be controlled by practical considerations. In the first place, there is a limit to the size of pulley that can be used on a line of shafting, set by the distance of the floor below or the ceiling above. Suppose the largest pulley that can be conveniently used on the driving shaft is three feet, obviously we cannot use above two feet on the driven. When the size of pulley most practicable for one of the shafts has been determined, the size of the other will be obtainable by the above rules.

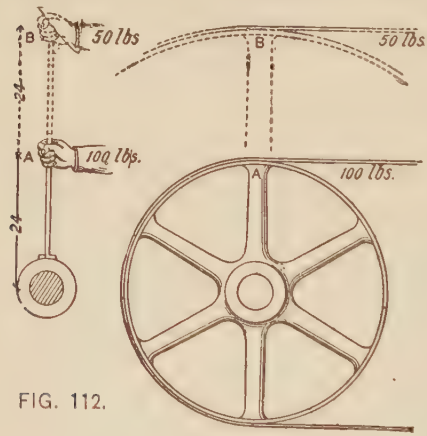


FIG. 112.

Q. 681—Does the amount of power to be transmitted have any bearing upon the subject?

A.—It does. If in Fig. 112 it takes a hundred pounds pull at *A* to turn the shaft, it could be moved with 50 pounds by placing the pull at *B*, twice as far out upon the lever. A pulley is a continuous lever, and it will be readily seen that 50 pounds pull on the belt at *B*, Fig. 112, will move the shaft against as much resistance as 100 pounds at *A*. The hand at *B* would have to move through twice the space to turn the shaft a given number of degrees, as would the one at *A;* and the belt at *B* would have to run twice as swiftly to give the shaft the same number of revolutions per minute as would one on a pulley of half the diameter, as at *A*. As the strain which can be put on an inch width of belt is limited we must have twice as wide a belt to transmit the same power from the small pulley. It is therefore an advantage to have the pulleys as large as possible, or in other words to have the belts travel as fast as possible.

Q. 682—What is the practical limit of belt speed?

A.—Belts should not be run much over 5,000 and according to F. W. Taylor, the most economical speed is between 4,000 and 4,500 feet per minute.

Q. 683—How then is the capacity of a belt affected by its speed?

A.—It varies directly as the speed. A given belt will transmit twice the horse-power if its speed is doubled, within limits.

Q. 684—How is the capacity of a belt affected by its width?

A.—The capacity varies directly as the width. If a two-inch belt will transmit one horse-power, two such belts will transmit two horse-power, and this is true whether they are run separately or joined into a four-inch belt.

Q. 685—What other factor enters into the capacity of a belt?

A.—Its thickness. A double belt will transmit more power than a single, a three-ply more than a double.

Q. 686—How do you estimate the capacity of a belt?

A.—It is assumed that a belt one inch in width will transmit a horse-power at the following speeds:

Single laced, 1,000 ft. per min.
" cemented 800 " " "
Double laced, 600 " " "
" cemented 400 " " "

Then as the power is directly as the width and speed we have

$$\frac{W \times S}{e} = \text{Horse-power}$$

Where W = width in inches
S = feet per min.
e = constant as above (1000 for single laced, etc.).

RULE:—*Multiply the width of the belt in inches by its speed in feet per minute and divide by 1000 for single laced belts, 800 for single cemented, 600 for double laced, and 400 for double cemented.*

EXAMPLE:—How much power will a 10-inch double laced belt running over a five foot pulley which makes 215 revolutions per minute transmit?

A.—A five foot pulley at 215 revolutions per minute would have a speed of $5 \times 3.1416 \times 215 = 3{,}377.22$ feet per minute.

This multiplied by the width, 10, and divided by the constant for a double laced belt, 600, would give

$$\frac{3377.22 \times 10}{600} = 56.287 \text{ horse-power.}$$

Q. 687.—How could this be worked right from the diameter?

A.—The operation followed above is

$$\frac{D \times 3.1416 \times W}{c}$$

If we divide 3.1416 by the constant we shall have simply to multiply the diameter by that quotient and by the width. For instance, with a single laced belt the constant is 1000, and

$$\frac{D \times 3.1416 \times W}{1000} = D.\ W.\ 0031416.$$

If instead of 1000 we used 1047 it would divide 3.1416 three times, and the formula would be

$D\ W\ .003$ = horse power.

By slight changes in the constants of the other belts we get,

For single laced	.003
" " cemented	.004
" doubled laced	.005
" " cemented	.008

Rule:—Multiply the diameter of the pulley in feet by the width of the belt in inches and by the above constant.

Both rules are approximations and one is probably as correct as the other.

Q. 688.—Do these rules give the maximum driving power of the belts?

A.—No. They give the power which the belt ought to give when working under good average conditions, arc of contact, etc., without slippage, fatigue, or excessive wear.

Q. 689.—What do you mean by the "arc of contact?"

A.—The proportion of the total circumference of the pulley in contact with the belt.

Q. 690.—What effect has the arc of contact on the amount of power which can be transmitted?

A.—The power varies directly with the arc of contact, and will be only one-half as great when the belt wraps one-quarter around the pulley as when it covers one-half of its circumference.

Q. 691 —Give a rule for finding the width of belt required to transmit a given horse-power which takes account of the arc of contact.

A.—Samuel Webber, M. E., gives the following from his practice:

For single belts

$$W = \frac{\text{H.P.} \times 5500}{\text{velocity} \times \text{contact}}$$

For double belts

$$W = \frac{\text{H.P.} \times 3660}{\text{velocity} \times \text{contact}}$$

where the velocity is in feet per minute and the contact in feet of contact on the smaller pulley.

Rule:—Multiply the horse power by 5,500 for single or 3,660 for double belts and divide by the product of the velocity in feet per minute and the arc of contact on the smaller pulley in feet.

Example:—How large a double belt would be required to transmit 160 horse-power at 3,200 feet per minute with 7.5 feet of contact on the smaller pulley?

$$W = \frac{160 \times 3660}{3200 \times 7.5} = 24 \text{ inches.}$$

Q. 692 —In what other way may the capacity of a belt be calculated?

A.—By the square feet of belt passing over the pulleys per minute.

Q. 693 —How many square feet per minute are required per horse-power?

A.—It has been said (see Q. 686) that a double laced belt will transmit a horse-power for each inch in width at 600 feet per minute belt velocity. This would be a strip one inch wide and 600 feet long, or 50 square feet, passing over the pulleys per minute per horse-power. Figuring in this way we get for the varieties of belt given

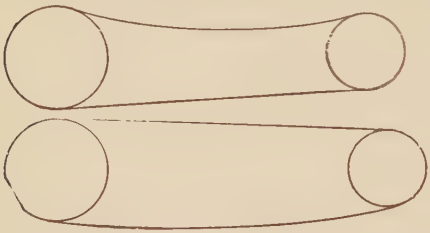
Single laced	83⅓	sq. ft. per	min.
" cemented	66⅔	"	"
Double laced	50	"	"
" cemented	33⅓	"	"

Q. 694 —What can be said of belt formulæ in general?

A.—They are empirical, expressing the results of practice rather than a general law. The most that they can do is to give a general idea of what is required under average conditions. When the distance between shaft centers is small, with

pulleys of widely varying diameter, giving a small arc of contact, liberal allowances must be made.

Q. 695—How much wider should the pulley be than the belt?



FIGS. 113 AND 114.

A.—At least 20 per cent. wider, or 1 $\frac{1}{5}$ times as wide.

Q. 703—With a 10-inch belt, how wide should the pulley be made?

A.—10 × 1 $\frac{1}{5}$ = 12 inches.

Q. 696—How much does leather belting shrink?

A.—Somewhat over 6 per cent. of its length.

Q. 697—Which is preferable, a narrow and thick belt, or a wide and thin one?

A.—The narrow and thick.

Q. 698—Give a rule of thumb for locating a jack shaft to secure good belting conditions.

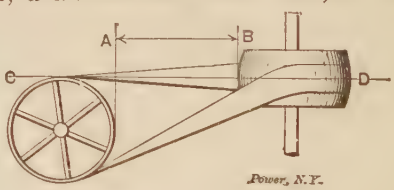


FIG. 115.

A.—Make the distance between centers not less than 2$\frac{1}{2}$ times the diameter of the large pulley. The small pulley should be at least one-third the diameter of the large to secure a proper arc of contact.

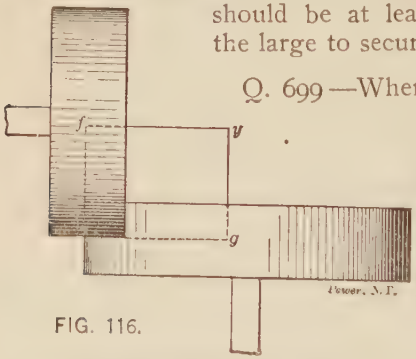


FIG. 116.

Q. 699—Where should the tight side of the belt be run?

A.—On the bottom, so that the slack may hang down and bring more of the belt into contact with the pulleys, as in Fig. 113, instead of less, as in Fig. 114.

Q. 700—What are the conditions necessary to the successful running of a quarter-turn belt?

A.—The distance A B, between the near faces of the pulleys Fig. 115, must not be less than four times the width of the

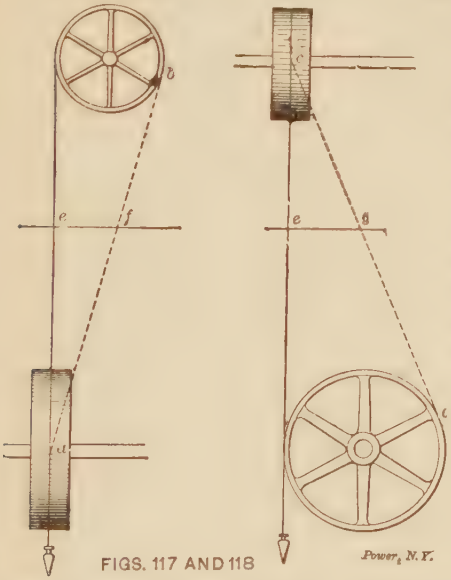
belt. The pulleys must be placed so that the belt will lead off from the face of one on to the center of the face of the other, i. e., so that a plane C D, cutting the center of one pulley, will be tangent to the other.

Q. 701 —How would you set the pulleys for a quarter-turn belt driving between two stories?

A.—Drop a plumb-line from the center of the face of the upper pulley, bore a hole in the floor so that the line can pass through, and locate the lower pulley so that the plumb-line will cut it centrally, as in Fig. 117. The line should just touch the edge of the lower pulley, as in Fig. 118. If it does not, move the upper pulley along the shaft until it will.

Q. 702 —How would you lay out the holes in the floor for the belt?

A.—Lay out the transmission to scale, as in Figs. 117 and 118. The line representing the plumb-line will be the center of the vertical belt. Draw the diagonal lines a b and c d.



FIGS. 117 AND 118

Draw the pulleys in plan to the same scale, as in Fig. 116. The point of intersection, x, of the two pulleys marks on the plan the position of the plumb-line. Lay off the distance x f on the plan equal to the distance e f in Fig. 117, and the distance x g on the plan equal to e g in Fig. 118. Complete the parallelogram as in Fig. 116, and the point y will mark the center line of the returning side of the belt. Bore a hole at this point and pass a piece of tape or narrow belt around the pulleys, which will indicate the obliquity of the holes. These positions are those the belt will assume when tight and at rest. Allowance must be made for the sag movement of the belt when at work.

Q. 703 —Show another method of driving around a corner.

A.—It can be done with a tight and a loose pulley on each shaft, as in Fig. 119. The loose pulley will run in the opposite drection from the tight, and the shaft may be driven in either direction by using the corresponding pulley as the tight one.

Q. 704—How should a belt be laced?

A.—There are various methods of lacing, each of which has its advocates and some of which have special advantages for particular work. Several of these methods are shown in Figs. 123.

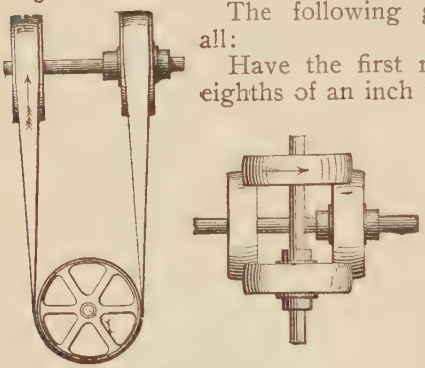


FIG. 119

The following general directions apply to all:

Have the first row of holes at least seven-eighths of an inch from the end of the belt.

Have the second row at least one inch from the first row.

Have the end holes at least three-quarters of an inch from the edge of the belt.

For large belts increase these distances somewhat. Space the holes equally between the end ones located as above so that the laces will be from one-half inch to an inch apart, according to the width of the belt. The hinge-joint shown in 15, Fig. 123, is specially adapted to fast running belts and belts passing over small pulleys where flexibility is a specially desirable feature.

Q. 705—How would you splice a belt?

A.—Cut the belt as shown in either of Figs. 120, 121 and 122. The V-splice, Fig. 121, should be used on triple and quadruple belts and when idler pulleys are used Fig. 122 is especially for rubber belts. For double belting, rubber or leather, for all belts up to 10 inches wide,

FIGS. 120, 121 AND 122

make the splice 10 inches long. From 10 to 18 inch belts make the splice as long as the belt is wide; 18 inches being the longest splice required for a double belt.

Q. 706—How would you make the joint of rubber belts?

A.—Coat it with uncured rubber in solution and vulcanize it after it is in place by means of steam heated clamps.

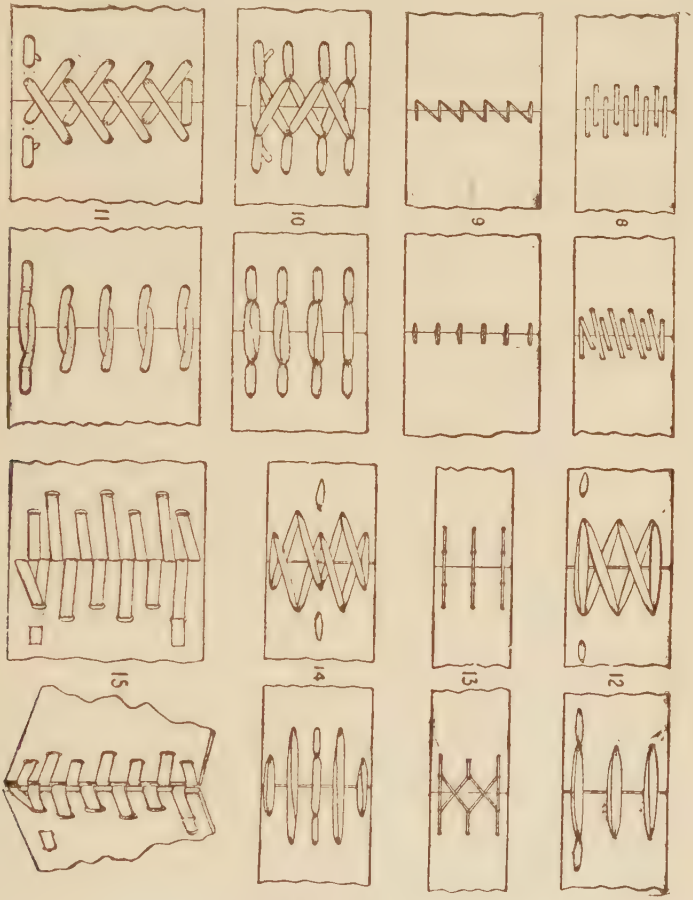


FIG. 123.

Q. 707—Upon what does the driving power of a belt depend?

A.—Upon the difference in the tension between the tight and slack sides.

Q. 708—What limits this unbalanced tension?

A.—If it becomes greater than the friction of the belt on the pulley the belt will slip and prevent any further increase of driving force.

Q. 709—Upon what does the point at which slipping will commence depend?

A.—Upon the total pull and the friction between the surfaces. For example, if we hang a piece of belt over a pulley and weight it on both ends, as shown in Fig. 124, the force tending to turn the pulley around will be the difference between the weights W and w. If there is considerable resistance to the movement of the pulley the belt may slip on its surface before it commences to turn. The amount of difference which may exist between W and w before slipping commences depends first on the nature and condition of the surfaces. If the belt were hard and shiny, and the pulley smooth and slippery, the belt would move on the pulley with less difference than if the pulley were dry and the belt pliable and sticky.

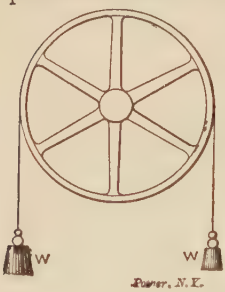


FIG. 124.

Again, we could increase the difference between W and w by increasing both of the weights, i. e., increasing the total pressure on the pulley. This would be equivalent to taking up a belt, or putting more initial tension into it, which is frequently done to prevent slipping. For a given conditon of the surfaces the ratio of the difference between W and w to the total weight will be constant.

Q. 710—What is this ratio called?

A.—The coefficient of friction.

Q. 711—Explain more fully what is meant by the coefficient of friction.

A.—If a block B be placed on a table, as in Fig. 125, and a weight w suspended over a frictionless pulley just sufficient to keep the block in motion, then the ratio of the weights of w and B will be the coefficient of friction between the block and the surface on which it slides. If the block weighed ten pounds and the weight two and a half, the coefficient of friction would be $\frac{25}{10} = .25$.

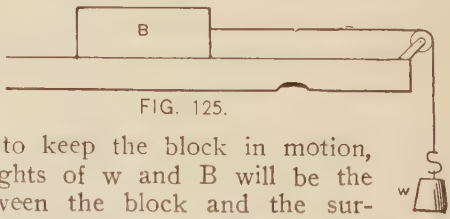


FIG. 125.

Q. 712—Upon what does the coefficient of friction depend?

A.—Simply upon the nature and condition of the surfaces.

Q. 713—Does it not depend upon the extent of the surfaces in contact?

A.—No. If you put a brick upon a board, as in Fig. 126, and elevate the board until the brick begins to slide, you will find that the height h to which you must lift the end will be the same whether you place the brick on its face, edge, or end. The coefficient of friction will be the fraction made by writing the length of the base b over the length of the board.

Q. 714—Does the speed make any difference in the coefficient of friction?

A.—Not for ordinary velocities.

Q. 715—Applying these principles, would a belt slip any quicker on an 18-inch pulley than on a 24-inch one, other conditions being equal?

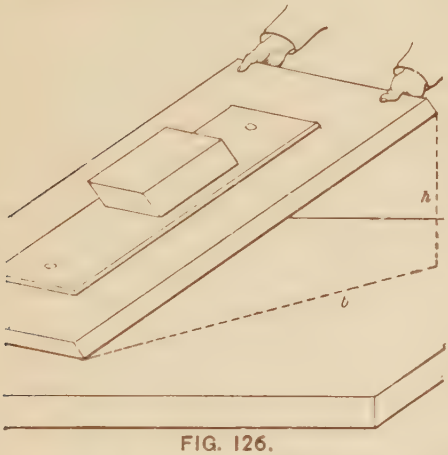


FIG. 126.

A.—No. The slip depends on the coefficient of friction and the total weight or pressure between the surfaces. Neither of these is changed by changing the diameter. The pressure per square inch is changed, just as in the case of the brick, but the total pressure is not.

Q. 716—Does the width of the belt make any difference?

A.—Other conditions being equal, no, for the same reason as before. But if you double the width you double the pull or pressure on the surface with the same initial tension, so that a wider belt is a cure for slipping.

Q. 717—What is the coefficient of friction between a leather belt and a cast-iron pulley, both belt and pulley surface being in average condition?

A.—About .28, as determined by M. Morin.

Q. 718—What is the coefficient of friction of leather belts in ordinary condition on wooden pulleys?

A.—About .47, by the same authority.

Q. 719—What are the advantages of high belt speed?

A.—Less belting required and less pull in the bearings, consequently less friction and liability to get out of line in the shafting.

Q. 720—What limits the speed at which belting may be run?

A.—The allowable rim speed of the pulleys, which should not exceed 90 feet per second. The centrifugal force also of the belt itself begins to interfere with its efficiency at speeds exceeding 5,000 feet per minute.

Q. 721—Upon what does the amount of power required to run a shaft in a bearing depend?

A.—Upon the coefficient of friction between the bearings surfaces, the total pressure between those surfaces, and the distance through which any point on the surface of the shaft is carried in a given time. Take the bearing shown in Fig. 127; assume the weight of the shaft in the bearing to be 1000 pounds; suppose the coefficient of friction to be .1, then it would take a pull of 100 pounds at any point on the circumference as A to move the shaft. To turn it around once this force of 100 pounds would have to be exerted through a space equal to the circumference, and the power in foot pounds per minute would be 100 multiplied by the circumference and by the revolutions per minute.

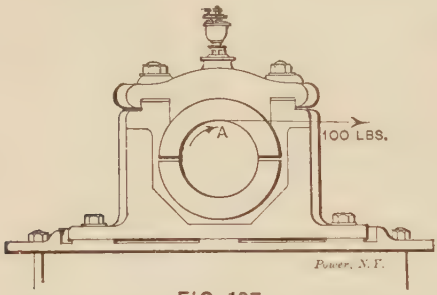


FIG. 127.

Q. 722—In this case, then, the power is proportional to the diameter and the speed?

A.—Yes.

Q. 723—But it has just been said that friction is independent of surface and velocity.

A.—So the frictional resistance is, but resistance is not power, nor is the force required to overcome it, except as that force is exerted through the space, and the power exerted is proportional to the space moved through.

Q. 724—Then the power required to run a shaft in its bearing is proportional to its diameter, that is, twice the diameter would require twice the power?

A.—Yes, the weight remaining constant; but increasing the diameter increases the weight also, so that the power increases faster than the diameter.

Q. 725—Then it is advisable to use shafting as small as possible?

A.—Yes, but the shaft must have sufficient stiffness or you will lose more from lack of alignment than you gain from reducing diameter.

Q. 726—How do you determine the size of shaft necessary to transmit a given horse-power?

A.—D. K. Clark gives the following formulae:

$$\text{Wrought Iron} \quad \frac{d^3 s}{190} = \text{H. P.} \quad \sqrt[3]{\frac{190 \text{ H. P.}}{s}} = d$$

$$\text{Steel} \quad \frac{d^3 s}{92} = \text{H. P.} \quad \sqrt[3]{\frac{92 \text{ H. P.}}{s}} = d$$

RULES:—*To find the maximum horse-power of a shaft within good working limits, multiply the cube of the diameter in inches by the speed in turns per minute and divide by 190 for wrought iron or by 92 for steel. The quotient is the horse-power.*

To find the diameter of a shaft capable within good working limits of transmitting a given horse-power:

Multiply the horse-power by 190 for wrought iron or by 92 for steel, and divide by the speed in turns per minute. The cube root of the quotient is the diameter in inches.

To find the speed required for transmitting a given horse-power within good working limits:

Multiply the horse-power by 190 for wrought iron or by 92 for steel and divide the product by the cube of the diameter in inches. The quotient is the speed in turns per minute.

Q. 727—How else can the size of a shaft necessary to transmit a given power be determined?

A.—By the use of the accompanying table No. XXIII, which was calculated by Hans Birkholz, M.E., of Milwaukee, Wis.:

EXPLANATION OF TABLE.

A) In each space in the table three figures are given; the upper one for heavy, the lower for light and the center one for medium duty shafting.

Shafts should be selected from the table to correspond with the following conditions:

a) If no power is taken off by means of pulleys or gears, the shaft being subjected to torsional strain only, use one size smaller than that indicated by lowest figure.

b) If ¼th of the power transmitted is taken off by means of pulleys, use shaft indicated by lower figure.

c) If ½ of the power transmitted is taken off by means of pulleys, use shaft indicated by middle figure.

d) If ¾ths of the power transmitted is taken off by means of pulleys, use shaft indicated by upper figure.

e) If the bearings are not more than 4 feet center to center and the entire power transmitted is taken off by means of pulleys, use shaft indicated by top figure.

f) Sections of shafts to which the power is applied or from which it is all taken off should be one size larger than that indicated by top figure.

g) If power is distributed by toothed gearing, it is advisable to use shaft one size larger than would be selected under conditions a to f.

B) For convenience the first horizontal column contains the H. P. for one revolution per minute only. This may be used profitably in the following two cases:

h) If the shaft and revolutions are given, multiply the H. P. given for one revolution in table (and selected therefrom as per a to g) by the number of revolutions given.

i) If a shaft is to be found for a given power and such a number of revolutions as is not indicated in table, first divide the given H. P. by the revolutions given. Now under consideration of conditions "a to g" find the shaft over such space in the first horizontal column which contains the result or a figure nearest to it.

k) For convenience in calculation the transmitting power of a steel shaft is put in the same square with the wrought iron shaft.

m) The transmitting power of a cold-rolled iron shaft may be calculated by finding the figure half way between the transmitting power of steel and wrought iron, or vice versa; the diameter may be taken as that half way between steel and wrought iron.

FORMULÆ BY WHICH THE TABLE IS COMPUTED.

a) Wrought Iron Shafts:
1—.008× $d^3 \times n$ for top figure.
2—.01 × $d^3 \times n$ " middle "
3—.013× $d^3 \times n$ " bottom "

b) Steel Shafts:
1—.011× $d^3 \times n$ for top figure.
2—.014× $d^3 \times n$ " middle "
3—.018× $d^3 \times n$ " bottom "

In these formulæ is
d = diameter of shaft in inches.
n = number of revolutions per minute.

Torsional maximum fiber strain in pounds per sq. inch allowed in above formulæ d.

a) Wrought Iron:	b) Steel:
1 = 2570 lbs.	1 = 3530 lbs.
2 = 3200 "	2 = 4490 "
3 = 4170 "	3 = 5770 "

EXAMPLE:

Wanted to transmit 75 horse power by a wrought iron shaft running 125 revolutions per minute.

TABLE XXIII.

	S. 1⅛ W.I.		S. 1 7/16 W.I.		S. 1 7/8 W.I.		S. 1 11/16 W.I.		S. 1 15/16 W.I.		S. 2 3/16 W.I.		S. 2 7/16 W.I.		S. 2 11/16 W.I.		S. 2 15/16 W.I
¼	.0091	.0066	.0183	.0134	.033	.0238	.053	038	.08	.058	.115	.084	.159	.116	.214	.155	.279	.203
	.0115	.0082	.0235	.0167	.0416	.0297	.067	.048	.102	.073	.147	.105	.203	.145	.272	.194	.355	.254
	.0148	.0107	.03	.0218	.0535	0386	086	062	.131	095	.189	.136	.261	.188	.35	.252	.456	.33
25	.228	.17	.457	34	.825	.59	1.32	.95	2.0	1.45	2.87	2.10	4.0	2.9	5.35	3.9	7.0	5.8
	.287	.21	.585	.42	1.04	.74	1.67	1.20	2.55	1.82	3 67	2.61	5.07	3.6	6.8	4.9	8.9	6.4
	.37	.27	75	.54	1.34	.97	2.15	1.56	3.27	2.37	4.72	3.40	6.5	4.7	8.75	6.3	11.4	8.2
30	.273	.20	.55	40	.99	:71	1.59	1.14	2.4	1.74	3.45	2.52	4.8	3.5	6.42	4.7	8.4	6.1
	.345	25	.705	.50	1.25	.89	2.01	1.44	3.06	2.18	4.4	3.14	6.09	4.3	8.15	5.8	10.6	7.6
	443	.32	.90	.65	1.6	1.16	2.58	1.87	3.93	2.88	5.7	4.10	7.8	5.6	10.5	7.5	13.7	9.9
35	318	.23	.64	.48	1.16	.83	1.85	1.33	2.3	2.03	4.02	2.94	5.6	4.0	7.5	5.4	9.8	7.1
	.402	.29	.82	.58	1.45	1.04	2.35	1.68	3.57	2.56	5.15	3.66	7.1	5.1	9.52	6.8	12.4	9.9
	.518	.38	1.05	.76	1.87	1.35	3.02	2.19	4.6	3.31	6.6	4.76	9.1	6.6	12.2	8.8	15.9	11.6
40	.363	.26	.73	.54	1.32	.95	2.12	1.52	3.2	2.32	4.6	3.36	6.4	4.6	8.56	6.2	11.2	8.1
	.46	.33	.94	.67	1.66	1.19	2.68	1.92	4.08	2.91	5.9	4.18	8.1	5.8	10.88	7.8	14.2	10.2
	.59	43	1.20	.87	2.14	1.55	3.44	2.49	5.24	3.78	7.56	5.45	10.4	7.5	14.0	10.0	18.2	13.2
45	.41	.30	.82	.60	1.48	1.07	2.38	1.71	3.6	2.61	5.18	3.78	7.15	5.2	9.6	7.0	12.6	9.1
	.518	.37	1.05	.75	1.87	1.34	3.02	2.16	4.69	3.37	6.6	4.70	9.15	6.5	12.2	8.8	15.9	11.4
	.665	48	1.35	.98	2.4	1.74	3.87	2.82	5.9	4.25	8.5	6.14	11.7	8.5	15.8	11.3	20.5	14.8
50	.155	.33	.915	.67	1.65	1.18	2.65	1.90	4.0	2.90	5.75	4.20	7.95	5.8	10.7	7.8	14.0	10.1
	.575	.41	1.17	.84	2.08	1.48	3.35	2.40	5.10	3.63	7.35	5.22	10.2	7.2	13.6	9.7	17.7	12.7
	74	54	1.50	1.09	2.67	1.93	4.3	3.12	6.55	4.73	9.45	6.80	13.0	9.4	17.5	12.6	22.8	16.4
55	.50	.37	1.02	74	1.81	1.30	2.92	2.09	4.4	3.19	6.3	4.62	8.75	6.4	11.8	8.8	15.4	11.1
	63	.45	1.29	.92	2.28	1.63	3.68	2.64	5.61	4.00	8.1	5.74	11.2	8.0	15.0	10.7	19.5	14.0
	812	.59	1.65	1 20	2.94	2.13	4.73	3.44	7.2	5.20	10.4	7.50	14.3	10.3	19.3	13.8	25.0	18.2
60	.546	40	1.1	.80	1.98	1.42	3.18	2.28	4.8	3.48	6.9	5.04	9.55	7.0	12.8	9.3	16.8	12.1
	.69	49	1.41	1.00	2.50	1.78	4.02	2.88	6.12	4.36	8.8	6.26	12.2	8.7	16.3	11.7	21.3	15.2
	89	.65	1.80	1 30	3.2	2.32	5.16	3.75	7.86	5.68	11.4	8.17	15.6	11.3	21.0	15.0	27.3	19.8
65	.592	43	1.19	.87	2.15	1.54	3.44	2.47	5.2	3.77	7.5	5.46	10.3	7.5	13.9	10.1	18.2	13.2
	.748	.54	1.53	1 09	2.70	1.93	4.36	3.12	6.63	4.73	9.55	6.79	13.2	9.4	17.7	12.6	23.1	16.5
	.96	.70	1.95	1.41	3.48	2.52	5.6	4.07	8.5	6.15	12.3	8.85	16.9	12.2	22.8	16.3	29.6	21.4
70	.638	.46	1.28	.94	2.31	1.68	3.71	2.66	5.6	4.06	8.03	5.88	11.2	8.1	15.0	10.9	19.6	14.2
	803	.58	1.64	1.17	2.91	2.08	4.69	3.36	7.14	5.10	10.3	7.32	14.2	10.2	19.0	13.6	24.8	17.8
	1.04	75	2.10	1.52	3.75	2.72	6.02	4.37	9.17	6.62	13.2	9.52	18.2	13.2	23.5	17.6	31.9	23.0
75	.683	.49	1.37	1.00	2.48	1.78	3.97	2.85	6.0	4.35	8.62	6.30	11.9	8.7	16.1	11.7	21.0	15.2
	.862	.62	1.76	1.25	3 12	2.23	5 03	3.60	7.65	5.45	11.00	7.83	15.2	10.9	20.4	14.6	26.6	19.0
	1.11	.80	2.25	1.63	4.02	2.90	6 45	4.69	9.8	7 10	14.2	10.2	19.5	14.1	26.3	18.9	34.2	24.6
80	.728	.53	1.46	1.07	2.64	1.90	4.24	3.04	6.4	4.64	9.2	6.72	12.7	9.3	17.1	12.4	22.4	16.2
	.92	.66	1 88	1.33	3.33	2.38	5.36	3.84	8.16	5.82	11.7	8.37	16.2	11 6	21.7	15.5	28.4	20.3
	1.18	86	2.40	1.74	4.26	3 09	6.90	5.00	10.48	7.60	15.1	10.9	20.8	15.1	28.0	20.1	36.5	26.3
85	.775	.56	1.55	1.14	2.8	2.02	4.5	3.23	6.8	4.93	9.76	7.14	13.5	9.9	18.2	13.2	23.8	17.2
	.976	.70	2.0	1.42	3.53	2.52	5.7	4.08	8.66	6.18	12.5	8.88	17.3	12.3	23.1	16.5	30.2	21.6
	1.26	.91	2.55	1.85	4.55	3.29	7.3	5.30	11.1	8.00	16.1	11.6	22.1	16.0	29.8	21.4	38.7	28.0
90	.82	.59	1.65	1.20	2.97	2.14	4.77	3.42	7.2	5.22	10.3	7.56	14.3	10.4	19.2	13.9	25.2	18.2
	1 03	.74	2.12	1.50	3.75	2.67	6.03	4.32	9.18	6.55	13.2	9.40	18.3	13.1	24.5	17.5	31.9	22.8
	1.33	.97	2.70	1.96	4.82	3.43	7.74	5.62	11.79	8.50	17	12.3	23.4	16.9	31.5	22.6	41.0	29.6
95	.865	.63	1.74	1.27	3.13	2.26	5.05	3.61	7.6	5.51	10.9	7.98	15.1	11.0	20.3	14.7	26.5	19.2
	1.09	.78	2.23	1.58	3.95	2.83	6.37	4.56	9.69	6.90	14.0	9.92	19.3	13.8	25.8	18.4	33.7	24.2
	1.41	1.02	2.85	2.07	5.08	3.68	8.2	5.94	12.5	9.00	17.9	12.9	24.7	17.9	33.3	23.8	43.3	31.2
100	.91	.66	1.83	1.34	3.3	2.38	5.3	3.80	8.0	5.80	11.5	8.40	15.9	11.6	21.4	15.5	27.9	20.3
	1.15	.82	2.35	1.67	4.16	2.97	6.70	4.80	10.2	7.27	14.7	10.5	20.3	14.5	27.2	19.4	35.5	25.4
	1.48	1.07	3.00	2.18	5.35	3.86	8.6	6.24	13.1	9.50	18.9	13.6	26.1	18.8	35.0	25.2	45.6	33.0
125	1.14	.83	2.28	1.67	4.1	2.97	6.6	4.75	10.0	7.26	14.4	10.5	20.0	14.5	26.7	19.4	35.0	25.4
	1.44	1.06	2.93	2.09	5.2	3.71	8.4	6.00	12.7	9.10	18.4	13.1	25.4	18.1	34.0	24.2	44.4	32.2
	1.84	1.34	3.75	2.72	6.7	4.85	10.7	7.80	16.4	11 8	23.6	17.0	32.6	23.5	43.7	31.3	57.0	41.0
150	1.36	.99	2.74	2.01	4.95	3.56	7.95	5.70	12.0	8.70	17.2	12.6	23.9	17.4	32.1	23.3	42.0	30.5
	1 72	1.25	3.52	2.50	6.25	4.45	10.1	7.20	15.3	10.9	22.0	15.7	30.5	21.7	40.8	29.0	53.3	38.0
	2.22	1 61	4.50	3.27	8.00	5.80	12.9	9.38	19.6	14.2	28.3	20.0	39.1	28.2	52.5	37.6	68.5	49.5
175	1.59	1.16	3.2	2.35	5.75	4.15	9.25	6.65	14.0	10.17	20.2	14.7	28.0	20.3	37.4	27.0	49.0	35.5
	2.02	1.44	4.1	2.92	7.3	5.20	11.7	8.40	17.8	12.7	25.6	18.3	35.5	25.2	47.5	34.0	62.0	44.5
	2.6	1.88	5.25	3.81	9.35	6.78	15.1	10.9	23.0	16.5	33.0	23.8	45.6	33.8	61.5	44.0	80.0	57.5
200	1.82	1.32	3.65	2.68	6.6	4.76	10.6	7.60	16.0	11.6	23.0	16.8	32.0	23.2	42.8	31.0	56.0	10.6
	2.3	1.65	4.7	3.35	8.3	5.94	13.4	9.60	20.4	14.5	29.4	21.0	40.8	29.0	54.4	39.0	71.0	56.1
	2.95	2.15	6.00	4.35	10.7	7.70	17.2	12.5	26.2	18.9	37.8	27.2	52.2	37.5	70.0	50.0	91.0	65.5
	S. 1⅛ W.I.		S. 1 7/16 W.I.		S. 1 7/8 W.I.		S. 1 11/16 W.I.		S. 1 15/16 W.I.		S. 2 3/16 W.I.		S. 2 7/16 W.I.		S. 2 11/16 W.I.		S. 2 15/16 W.I

TABLE XXIII (Continued).

	S. 3½ W.I.		S. 3⅝ W.I.		S. 3¾ W.I.		S. 3⅞ W.I.		S. 4 W.I.		S. 4⅛ W.I.		S. 4¼ W.I.		S. 4⅜ W.I.	
1	.336 .427 55	.244 .305 .397	.422 .538 .691	.308 .385 .500	.524 .667 .857	.38 .48 62	.64 .814 1.05	.466 .582 757	.77 .983 1.26	.562 .702 .913	.92 1.17 1.51	67 .837 1.09	1.09 1.39 1.78	79 .99 1.286	1.27 1.62 2.09	.927 1.16 1.5
25	8.4 10.7 13.7	6.1 7.6 9.9	10.5 13.4 17.3	7.4 9.6 12.5	13.1 16.7 21.4	9.5 11.9 15.5	16. 20.3 26.2	11.6 14.5 18.9	19.2 24.6 31.5	14. 17.6 22.8	23 29.2 38.	16.7 20.9 27.2	27.2 35. 44.5	19.7 24.7 32.2	31.7 40.5 52.2	23.3 29.0 37.6
30	10.0 12.8 16.5	7.3 9.2 11.9	12.7 16.1 20.7	9.5 11.5 15.0	15.7 20. 25.6	11.4 14.3 18.6	19.2 24.4 31.5	14.0 17.4 22.7	23.1 29.5 37.8	16.8 21.2 27.3	27.6 35. 45	20.2 25.1 32.7	32.7 41.7 53.4	23.7 29.7 38.6	38. 48.6 62.7	27.8 38.8 45.2
35	11.8 14.9 19.2	8.6 10.7 13.9	14.8 18.8 24.2	10.8 13.4 17.5	18.3 23.3 30	13.3 16.6 21.6	22.4 28.5 36.7	16.3 20.3 26.5	27 34.5 44.2	19.7 24.6 31.9	32.2 41. 53.	23.5 29.3 38.2	38. 48.6 62.4	27.6 34.7 45.1	44.5 56.8 73.	32.5 40.5 52.8
40	13.4 17.1 22.	9.8 12.2 15.9	16.9 21.5 27.6	12.3 15.4 20.0	21. 26.6 34.2	15.2 19.0 24.7	25.6 32.6 42.	18.6 23.3 30.4	30.8 39.3 50.4	22.5 28.2 36.5	36.8 46.8 60.4	26.8 33.5 43.6	43.6 55.6 71.2	31.6 39.6 51.5	50.8 64.8 83.6	37. 46.2 60.2
45	15.1 19.2 24.7	11.0 13.7 17.8	18.9 24.2 31.1	13.9 17.3 22.5	23.6 30. 38.5	17.1 21.4 27.8	28.8 36.7 47.2	20.9 26.0 44.2	34.6 44.3 56.8	25.3 31.6 41	41.3 52.5 68	30.2 37.6 49	49. 62.5 80.	35.5 44.5 58.	57.2 73. 94.	41.7 52. 67.8
50	16.8 21.3 27.5	12.2 15.2 19.8	21. 26.9 34.5	15.4 19.2 25.0	26.2 33.5 42.8	19.0 23.7 30.9	32. 40.7 52.5	23.3 29.0 47.8	38.5 49.1 63	28.2 35.2 45.6	43 58.5 75.5	33.5 41.9 54.4	54.5 69.5 89	39.5 49.5 64.3	63.5 81. 104	46.3 58. 75.2
55	18.5 23.5 30.2	13.4 16.7 21.8	23.2 29.6 38.	16.9 21.1 27.5	28.8 36.6 47	20.9 26.2 34.0	35.2 44.8 57.7	25.6 32.0 41.7	42.3 54 69.2	30.9 38.6 50.1	50.6 64.2 83	36.8 46. 59.8	60. 76.5 98.	43.5 54.5 71	70 89. 115	51 63.8 82.8
60	20.2 25.6 33.	14.6 18.3 23.7	25.3 32.2 41.5	18.5 23.0 30.0	31.4 40. 51.2	22.8 28.5 37.2	38.4 48.9 63	27.9 35.0 45.5	46.2 59. 75.6	33.8 42.2 54.8	55.2 70 90	40.2 50.2 65.3	65.4 83.4 106.8	47.5 59.5 77.2	76. 97.2 125.	55.7 69.6 90.5
65	21.8 27.7 35.7	15.8 19.8 25.7	27.4 35. 44.9	20.0 25.0 32.5	34. 43.3 55.5	24.7 30.8 40.3	41.6 53 68.2	30.3 37.8 49.2	50. 64 82	36.5 45.6 59.2	59.8 76 98	43.5 54.3 70.8	71. 90. 115	51.4 64.5 83.7	82.2 105 136.	60.3 75.2 98.
70	23.5 29.8 38.4	17.1 21.3 27.7	29.5 37.6 48.3	21.6 26.8 35.0	36.6 46.7 60	26.6 33.3 43.4	44.8 57 73.5	32.6 40.7 53.0	54 69 88.2	39.3 49.2 63.8	64.5 82 105	46.8 58.5 76.3	76 97 124	55.3 69.4 90.2	88.7 113 146	65 81. 105
75	25.2 32.0 41.2	18.3 22.8 29.7	31.6 40.2 51.8	23.2 28.7 37.5	39.3 50. 64	28.5 35.7 46.5	48 61. 78.5	35.0 43.6 56.8	57.3 74 94.5	42.1 52.6 68.3	69 87.8 113	50.2 62.7 81.8	81.5 104. 133.	59.2 74.3 96.5	95 121. 156	69.5 87. 113.
80	26.8 34.1 44.	19.5 24.3 31.7	33.7 43 55.2	24.7 30.7 40.0	42. 53.3 68.3	30.5 38.0 49.6	51.2 65 84.	37.3 46.5 60.8	61.6 78.8 100	45 56.2 73.	74. 93.5 120	53.6 67 87.2	87 111. 142	63.2 79.3 103.	101 130. 167	74.2 92.8 121.
85	28.5 36.3 46.7	20.7 25.8 33.7	35.8 45.6 58.8	26.2 32.6 42.5	44.5 56.6 72.8	32.4 40.4 52.7	54.4 69. 89.	39.6 49.4 64.2	65.2 83.7 107.	47.8 59.6 77.5	78.5 99.3 128	56.8 71.2 92.5	92.5 118. 151	67.2 84.3 109.	108. 138. 177	79. 98.5 128.
90	30.2 38.4 49.5	21.9 27.3 35.7	37.9 48.3 62.2	27.7 34.5 45.0	47 60. 77.	34.3 43.8 55.8	57.6 73. 94.5	42.0 52.3 68.0	69.2 88.7 113	50.7 63.2 82	83 106 136.	60.3 75.3 98.	98. 125. 160.	71.2 89.3 116.	114. 146. 188	83.5 104. 135.
95	31.8 40.5 52.2	23.2 28.8 37.7	40. 51. 65.6	29.3 36.5 47.5	49.6 63.4 81.5	36.2 45.2 59	60.8 77.2 99.5	44.3 55.2 72.0	73. 93.5 120.	53.5 66.6 86.5	87.5 111 143.	63.6 79.5 103.	103. 132. 169.	75.1 94.2 122.	120. 154. 198.	88. 110. 143.
100	33.6 42.7 55.	24.4 30.5 39.7	42.2 54. 69.1	30.8 38.4 50.0	52.4 66.7 85.7	38.1 47.6 62.0	64. 81.4 105.	46.6 58.2 76.0	77. 98. 126.	56.2 70.2 91.3	92 117 151	67. 83.7 109.	109. 139. 178.	79. 99. 128.	127 162. 209.	92.7 116. 150.
125	42.0 53.4 69.	30.5 38.0 49.6	52.6 67 86.5	38.5 48.0 62.5	65.5 83.3 107.	47.8 59.5 77.6	80. 102. 131.	58.2 72.5 96.0	96. 123. 157.	70. 86.5 114.	115 146. 188.	83.7 104. 136.	136. 175. 223.	98.8 123. 161.	159. 203. 261.	113. 144. 188.
150	50.4 64. 82.2	36.6 46. 59.5	63.5 81. 104.	46.2 57.5 75.0	78.5 100. 128.	57.2 71.5 92.8	96. 122. 157.	69.8 87.0 114.	115. 147. 189.	84.2 105. 137.	129. 175. 226.	101 125. 163.	163. 208. 267.	118. 148. 193.	190. 243. 312.	139. 174. 225.
175	58.8 74.8 96.	42.7 53. 69.4	74. 94. 121.	54. 67.4 87.5	92. 116. 150.	66.5 83.0 108.0	112. 142. 184.	81.4 102. 133	135. 172. 220.	98.3 123. 159.	161 205. 264.	117 146. 190.	190. 243. 311	139. 173. 225	222. 284. 365.	162. 203. 263
200	67.2 85.4 110.	48.8 61.0 79.4	84. 108. 138.	62.0 76 8 100.0	100. 133. 171.	76.2 95.0 124.0	128. 162. 210.	93.0 116. 151.	154. 197. 252.	112. 140. 182.	184. 234. 302.	134. 167. 218.	218. 278. 356.	159. 198. 257.	254. 324. 418.	185. 232. 300.
	S. 3½ W.I.		S. 3⅝ W.I.		S. 3¾ W.I.		S. 3⅞ W.I.		S. 4 W.I.		S. 4⅛ W.I.		S. 4¼ W.I.		S. 4⅜ W.I.	

TABLE XXIII (Continued).

	S. 5⅜ W.I.		S. 5½ W.I.		S. 6 W.I.		S. 6½ W.I.		S. 7 W.I.		S. 7½ W.I.		S. 8 W.I.		S. 8½ W.I.	
1	1.71 2.17 2.8	1.24 1.55 2.02	2.23 2.84 3.65	1.62 2.03 2.64	2.38 3.02 3.89	1.73 2.16 2.81	3.02 3.84 4.94	2.2 2.75 3.57	3.77 4.80 6.17	2.74 3.43 4.46	4.64 5.91 7.6	3.37 4.22 5.48	5.63 7.17 9.22	4.1 5.12 6.66	6.75 8.6 11.1	4.91 6.14 7.98
25	43. 54.2 70.	31.0 38.7 50.5	56. 71 91.2	40.5 51.0 66.0	59.5 75.5 97.2	43.2 54.0 70.0	75.5 96. 123	55. 68.5 88.0	94.2 120. 154.	68.5 86.0 111.0	116. 148. 190.	84.5 106.0 137.0	141. 180. 230.	103.0 143.0 166.0	170. 215. 280.	123.0 154.0 199.0
30	51.3 65 1 84	37.3 46.5 60.5	66.9 85.2 109	48.6 61.0 79	71.4 90 6 117	52.0 65.0 84.	90.6 115 148.	66.0 82.5 107	113. 144. 185	81.0 103.0 134.	139. 177. 228.	101.0 127. 164.	169. 215. 277	123. 154. 199.	202. 258. 333.	147. 184. 239.
35	60. 75.5 98.	43.5 54.4 70.7	78. 99.5 128	56.8 71. 92.2	83. 106 136.	60.5 75. 98.	105. 134. 173.	77 96. 125	132. 168. 215.	96. 120. 156.	162. 207. 265.	118. 148. 192.	198. 251. 323.	143. 179. 233.	237. 302. 388.	172. 215. 278.
40	68.4 86.8 112.	49.7 62. 80.8	89.2 114. 146.	65. 81. 106.	95.2 121. 156.	69 86 112.	129.8 154. 198.	88. 110. 143.	151. 192. 247	109. 137. 178.	186. 236. 304.	135. 169. 218.	225. 287. 369.	164. 205. 266.	270. 362. 444.	196. 246. 318.
45	77. 97.5 128.	56. 70. 91.	102. 128. 164.	73. 91. 119.	107. 135. 176.	78. 97. 126.	136. 173. 223.	99. 123. 160.	170. 216. 277.	123. 154. 200.	208. 267. 342.	152. 190. 246.	255. 323. 415.	184. 232. 300.	305. 386. 497.	222. 276. 358.
50	85.5 108. 140.	62. 78. 101.	112. 142. 182.	81. 101. 132.	119. 151. 194.	86.5 108. 140.	150. 192. 247	110. 147. 178.	188. 240. 308.	137. 172. 222.	232. 295. 380.	169. 216. 274.	281. 358. 461.	205. 257. 333.	337. 430. 555.	246. 307. 398.
55	94. 119. 154	68.5 85. 111	123. 156. 202.	89. 111. 145	135. 166. 214.	95 118. 154	166. 212. 273.	121 151. 196.	207. 264. 317	151. 189. 245.	255. 325. 417.	185. 232. 302.	310. 395. 508.	226. 282. 366.	370. 472. 608.	270. 338. 438.
60	103. 130 168.	74.5 93. 121	134 170. 218.	97. 121. 158.	143. 181 234	104 129. 168.	181. 230. 296.	132. 165. 214	226. 288. 370.	164. 207. 267.	278. 354. 456.	203. 253. 328.	338. 430. 554.	246. 307. 400.	404. 516. 666.	294. 368. 478.
65	114. 41. 182.	81. 100. 131	145. 184. 238	105. 131. 172	155. 196. 253.	112. 140. 182.	196. 249. 321.	143. 178. 232.	245 312. 400.	178. 223. 289.	302. 384. 494.	219. 274. 356.	366. 466. 600.	267. 333. 433.	438. 559. 720.	318. 398. 518.
70	119 151. 196	87. 108 141	156. 199. 256.	114. 142. 185	167 211. 273.	121 151. 196.	211. 268. 346.	154. 192. 248.	263. 336. 432.	192. 240. 312.	325. 414. 532.	236. 295. 384.	394. 503. 646.	287. 359. 466.	472. 602. 776.	343. 430. 558.
75	128. 162. 210	93. 116. 152.	167. 212 274.	122. 152. 198.	179. 226. 292.	130. 162. 211.	226. 288. 370.	165. 206 267	282. 360. 462	206. 257. 334.	348. 443. 570.	253. 316. 411.	423. 538. 692.	307. 385. 500.	506. 645. 832.	368. 460. 598.
80	136 173. 224	100. 124 162.	178. 227 292.	130. 162. 212.	191. 241. 851.	138. 172. 224.	241. 307 395	176. 220 285.	301 383. 493.	219. 274. 356.	371. 473. 608.	270. 337 437.	451. 574. 738.	328. 410. 533.	540. 688. 886.	393. 490. 638.
85	145. 184 238	106. 132. 172	189. 242. 310.	138. 172. 224.	203. 256. 331	147. 183. 238.	256. 327. 420.	187. 234. 305.	320. 407 524.	233. 291. 378.	395. 502. 646.	287. 358. 465.	478. 610. 784.	348. 436. 566.	572. 730. 942.	417. 521. 678.
90	154. 195. 252.	112. 139. 182.	201. 255. 328.	146. 182. 238.	214. 271. 351.	156. 194. 252.	271. 356. 445.	198. 247 320.	339 432. 555.	247 308. 400.	418. 532. 684.	304. 379. 493.	507 645. 830.	368. 462. 600.	608. 775. 1000.	442. 552. 718.
95	162 205. 267.	118. 147. 192.	212. 269. 347.	154. 192. 251.	226. 286. 370.	164. 205. 267.	286. 365. 469.	209. 261. 338.	357 455. 586.	261. 326. 423.	442. 562. 720.	320. 401. 520.	535. 681. 878.	389. 487. 633.	641. 818. 1052.	466. 583. 758.
100	171. 217. 280.	124. 155. 202.	223. 284. 365.	162. 203 264.	238. 302. 389.	173. 216. 281.	302. 384. 494.	220 275. 357.	377. 480. 617.	274. 343. 446.	464. 591. 760.	336. 422. 548.	563. 717. 922.	410. 512. 666.	675. 860. 1110.	491. 614. 798.
125	214. 270. 350.	156. 194. 252.	280. 355. 466.	203. 253. 330.	298. 377 485.	217. 270. 350.	377. 480. 615	275. 343 445	461. 600. 770.	343. 430. 558.	580. 740. 950.	420. 527. 682.	705. 900. 1150	512. 640. 833.	850. 1075. 1400.	614. 770. 998.
150	256. 324. 420.	186. 233. 303.	336. 426. 546.	243. 304. 396.	357. 453. 582.	260. 324. 420.	450. 576. 741	330. 412. 535.	564. 720. 924.	410. 515. 668.	696. 885. 1140.	503. 632. 820.	843. 1174. 1383.	615. 770. 1000.	1011. 1290. 1665.	737. 920. 1193.
175	301. 379. 490.	218. 272. 354.	392. 497. 638.	285. 355. 462.	417. 529 680.	303. 378. 462.	529. 672. 861.	385 480. 615	659. 840. 1078.	480. 600. 780.	812. 1036. 1330.	590. 740. 960.	987. 1260. 1610.	718. 900. 1166.	1190. 1505. 1960.	860. 1075. 1398.
200	342. 434. 560.	248. 310. 404.	446. 568. 730.	324. 406. 526.	476. 604. 778.	346. 432. 562.	604. 768. 988.	440. 550. 714.	754. 960. 1234.	548. 686. 892.	928. 1182. 1520.	675. 844. 1096.	1126. 1434. 1344	820. 1024. 1332.	1350. 1720. 2220.	982. 1228. 1600.
	S. 5⅜ W.I.		S. 5½ W.I.		S. 6 W.I.		S. 6½ W.I.		S. 7 W.I.		S. 7½ W.I.		S. 8 W.I.		S. 8½ W.I.	

1st—For conditions as given under "a" and "b" above: With the finger we run along the lower line of the horizontal column for 125 rev. until we strike a figure nearest to 75 under the heading W. I. We find 77.6. The same is in the vertical column for 3⅝" shafts—hence we have for conditions as per "a" = 3⅜" and for "b" = 3⅝" shafts.

2d—For conditions as given under "c" we run along the middle line of the horizontal column for 125 rev. and stop at 72.5, which is in the column for 3⅞" shafts.

3d—For conditions as given under "d" and "e" we take the upper line and stop at 70 and get a 4⅛" shaft.

For conditions under "f" we get a 4⅜" shaft.

For conditions under "g" we get 3⅞", 4⅛", 4⅜" and 4⅝" shafts respectively from conditions b to f.

For steel we proceed in same manner and may readily be able to calculate which of the two is the more profitable.

Q. 728—What are the requirements of a shaft?

A.—It must be large enough to withstand the torsional or twisting strain tending to rotate it, stiff enough to withstand bending or deflection by the sidewise pull of belts, weight of pulley, etc., and large enough in the bearings to reduce the pressure per square inch to a safe point.

Q. 729—Why is it necessary to keep down the pressure per square inch in the bearings if the friction is independent of that quantity?

A.—The friction is independent of the area of the bearing surface so long as the condition of the surface is unchanged. If the pressure becomes too great the lubricant is pressed out and the surfaces cut.

Q. 730—What is regarded as a safe pressure in bearings?

A.—The pressure should not exceed 500 pounds per square inch on the axial section of the bearing.

Q. 731—What is the axial section?

A.—The longitudinal section at the axis of the shaft; the diameter multiplied by the length of the bearing.

Q. 732—Why do you not multiply by the half circumference instead of the diameter? This would give the area of bearing in contact with the shaft.

A.—Yes, but it can be readily seen that the shaft does not bear down on the sides, and it does not bear so heavily diagonally as on the bottom. The weight is distributed over an area equal to the projection of the inner surface of the box on a horizontal line, which projection equals the diameter.

Q. 733—But since a large diameter is a disadvantage, how else may we decrease the pressure per square inch on the bearings.

A.—By increasing the length.

Q. 734—Does increasing the length of a bearing add to the power required to overcome its friction?

A.—No; It simply reduces the load per square inch. The total load and the distance through which it is moved remain the same, hence the power is not affected. so long as the condition of the surfaces is maintained.

Q. 735—What is the ordinary length of boxes for shafting?

A.—From two to four times the diameter, usually four times on the smaller sizes.

Q. 736—How can the stiffness and torsional resistance of a shaft be increased without increasing its weight?

A.—By making it hollow.

Q. 737—Why?

A.—The material in the exact center of the shaft is of no use for resisting either torsion or bending, and not until some

TABLE XXII.

A.—Solid Shaft. Diam. Inches.	Equiv. Hollow Shaft.		Weight per foot.	
	Inside Diam. Inches.	Outside Diam. Inches.	Solid.	Hollow.
1	1	1¼	2.65 lbs.	1.52 lbs.
1½	1½	1⅞	5.97 "	
2	2	2½	10.6 "	6.7 "
2½	2½	3⅛	16.7 "	
3	3	3¾	24.0 "	13.3 "
3½	3½	4⅜	32.5 "	
4	4	5	42.5 "	24.3 "

distance from the center is reached do the fibers have an appreciable effect. A hollow shaft containing the same amount of metal disposed at a greater average distance from the center is therefore better adapted to resist these strains than a solid one.

Q. 738—How do the weights per foot of hollow and solid shafts compare, for the same strength?

A.—As shown in Table XXII.

Q. 739—What are the advantages of hollow shafting?

A.—Being lighter the bearings can be spaced further apart; being larger in diameter it affords a better clamping surface for pulleys; it is less liable to be sprung in handling and shipping, and being lighter in the bearings requires less power.

Q. 740—Is not the increased diameter a disadvantage so far as friction is concerned (see Q. 730)?

A.—The diameter in the boxes is reduced by inserting for each journal a short piece of solid shaft.

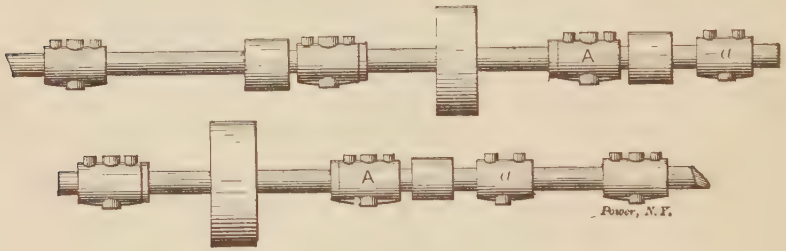
Q. 741—What should be the length between hangers for solid shafting?

A.—From 6 to 8 feet when lightly weighted.

Q. 742—How much may this distance be increased for hollow shafting?

A.—To ten feet.

Q. 743—What precautions should be observed in regard to location of pulleys?



FIGS. 128 AND 129.

A.—Locate pulleys near hangers where possible so that the shaft may be sprung as little as possible by the pull of the belt. Where the belt is large or the duty severe it is well to put a hanger on both sides of the pulley which receives the power. At all events that length of shafting upon which the power is received should have at least two hangers, as in Figs. 128 and 129, where it will be seen that if in either case the hanger A was located at "a" the coupling would be subjected to a sidewise strain.

Q. 744—How do the standard sizes of shafting vary?

A.—The sizes advance by quarter inches up to four inches, then by half inches, but the shaft is always one-sixteenth less than the quarter, half, or even inch. A two inch bar when turned and finished becomes a $1\frac{15}{16}$ shaft. The size below it is a $1\frac{11}{16}$ turned from a $1\frac{3}{4}$ inch bar, and the next size above is $2\frac{3}{16}$ turned from a $2\frac{1}{4}$ inch bar.

Q. 745—What is meant by shafting being out of line?

A.—That the center of the shaft is not in the same vertical plane throughout its length. If a line were stretched tightly beside that shaft, equidistant at both ends, measurements made

between the shaft and line should be equal at all points. If not, the shaft is out of line.

Q. 746—What is meant by a shaft being out of level?

A.—That the center of the shaft is not in the same horizontal plane throughout its length, i. e., if a line is stretched horizontally above or below the shaft the distance between the shaft and the line should be the same wherever measured. If not, the shaft is out of level.

FIGS. 130 and 131.

Q. 747—How would you proceed to determine if a shaft was in line?

A.—By hanging several weighted lines, as in Fig. 130, over the shaft and sighting by them. If they are not all in line the hangers must be adjusted to bring them so.

Q. 748—Why would not a single line suffice?

A.—Unless particular care is used it may hang to one side of the center, as in Fig. 131. It is more convenient in shafts of varying diameter, and sufficiently accurate if attention is paid to this point.

Q. 749—What precaution must be used?

A.—At least one of the lines must be left upon the length of the shaft already lined, so that any movement of that length caused by moving the next may be observed. A little ingenuity will be required where the diameter of the shaft changes.

Q. 750—How would you proceed to level a shaft?

A.—This may be done with a long spirit level or a long straight edge to which a spirit level may be applied.

Q. 751—To facilitate these adjustments what hangers should be used?

A.—Those providing for both a vertical and horizontal movement of the boxes.

Q. 752—How are shafts prevented from moving endwise?

A.—By collars arranged to run against a stationary bearing.

Q. 753—Should these be set tightly?

A.—No; they should allow the shaft to have a slight motion endwise to secure a better distribution of the lubricant and prevent wearing in grooves; also to allow for differences in length from expansion.

TABLE No. XXIV.—Numbers, or Diameters of Circles, Circumferences, Areas, Squares, Cubes, Square Roots and Cube Roots.

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
1	3.1416	0.7854	1	1	1.000	1.000
2	6.28	3.14	4	8	1.414	1.259
3	9.42	7.07	9	27	1.732	1.442
4	12.57	12.57	16	64	2.000	1.587
5	15.71	19.63	25	125	2.236	1.709
6	18.85	28.27	36	216	2.449	1.817
7	21.99	38.48	49	343	2.645	1.912
8	25.13	50.27	64	512	2.828	2.000
9	28.27	63.62	81	729	3.000	2.080
10	31.42	78.54	100	1,000	3.162	2.154
11	34.56	95.03	121	1,331	3.316	2.223
12	37.70	113.10	144	1,728	3.464	2.289
13	40.84	132.73	169	2,197	3.605	2.351
14	43.98	153.94	196	2,744	3.741	2.410
15	47.12	176.71	225	3,375	3.872	2.466
16	50.26	201.06	256	4,096	4.000	2.519
17	53.41	226.98	289	4,913	4.123	2.571
18	56.55	254.47	324	5,832	4.242	2.620
19	59.69	283.53	361	6,859	4.358	2.668
20	62.83	314.16	400	8,000	4.472	2.714
21	65.97	346.36	441	9,261	4.582	2.758
22	69.11	380.13	484	10,648	4.690	2.802
23	72.26	415.48	529	12,167	4.795	2.843
24	75.40	452.39	576	13,824	4.898	2.884
25	78.54	490.87	625	15,625	5.000	2.924
26	81.68	530.93	676	17,576	5.099	2.962
27	84.82	572.56	729	19,683	5.196	3.000
28	87.96	615.75	784	21,952	5.291	3.036
29	91.11	660.52	841	24,389	5.385	3.072
30	94.25	706.86	900	27,000	5.477	3.107
31	97.39	754.77	961	29,791	5.567	3.141
32	100.53	804.25	1,024	32,768	5.656	3.174
33	103.67	855.30	1,089	35,937	5.744	3.207
34	106.81	907.92	1,156	39,304	5.830	3.239
35	109.96	962.11	1,225	42,875	5.916	3.271
36	113.10	1017.88	1,296	46,656	6.000	3.301
37	116.24	1075.21	1,369	50,653	6.082	3.332
38	119.38	1134.11	1,444	54,872	6.164	3.361
39	122.52	1194.59	1,521	59,319	6.244	3.391
40	125.66	1256.64	1,600	64,000	6.324	3.419
41	128.80	1320.25	1,681	68,921	6.403	3.448
42	131.95	1385.44	1,764	74,088	6.480	3.476
43	135.09	1452.20	1,849	79,507	6.557	3.503
44	138.23	1520.53	1,936	85,184	6.633	3.530
45	141.37	1590.43	2,025	91,125	6.708	3.556
46	144.51	1661.90	2,116	97,336	6.782	3.583
47	147.65	1734.94	2,209	103,823	6.855	3.608
48	150.80	1809.56	2,304	110,592	6.928	3.634
49	153.94	1885.74	2,401	117,649	7.000	3.659
50	157.08	1963.50	2,500	125,000	7.071	3.684

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
51	160.22	2042.82	2,601	132,651	7.141	3.708
52	163.36	2123.72	2,704	140,608	7.211	3.732
53	166.50	2206.18	2,809	148,877	7.280	3.756
54	169.65	2290.22	2,916	157,464	7.348	3.779
55	172.79	2375.83	3,025	166,375	7.416	3.802
56	175.93	2463.01	3,136	175,616	7.483	3.825
57	179.07	2551.76	3,249	185,193	7.549	3.848
58	182.21	2642.08	3,364	195,112	7.615	3.870
59	185.35	2733.97	3,481	205,379	7.681	3.892
60	188.50	2827.43	3,600	216,000	7.745	3.914
61	191.64	2922.47	3,721	226,981	7.810	3.936
62	194.78	3019.07	3,844	238,328	7.874	3.957
63	197.92	3117.25	3,969	250,047	7.937	3.979
64	201.06	3216.99	4,096	262,144	8.000	4.000
65	204.20	3318.31	4,225	274,625	8.062	4.020
66	207.34	3421.19	4,356	287,496	8.124	4.041
67	210.49	3525.65	4.489	300,763	8.185	4.061
68	213.63	3631.68	4,624	314,432	8.246	4.081
69	216.77	3739.28	4,761	328,509	8.306	4.101
70	219.91	3848.45	4,900	343,000	8.366	4.121
71	223.05	3959.19	5,041	357,911	8.426	4.140
72	226.19	4071.50	5,184	373,248	8.485	4.160
73	229.34	4185.39	5,329	389,017	8.544	4.179
74	232.48	4300.84	5,476	405,224	8.602	4.198
75	235.62	4417.86	5,625	421,875	8.660	4.217
76	238.76	4536.46	5,776	438,976	8.717	4.235
77	241.90	4656.63	5,929	456,533	8.744	4.254
78	245.04	4778.36	6,084	474,552	8.831	4.272
79	248.19	4901.67	6,241	493,039	8.888	4.290
80	251.33	5026.55	6,400	512,000	8.944	4.308
81	254.47	5153.00	6,561	531,441	9.000	4.326
82	257.61	5281.02	6,724	551,368	9.055	4.344
83	260.75	5410.61	6,889	571,787	9.110	4.362
84	263.89	5541.77	7,056	592,704	9.165	4.379
85	267.03	5674.50	7,225	614,125	9.219	4.396
86	270.18	5808.80	7,396	636,056	9.273	4.414
87	273.32	5944.68	7,569	658,503	9.327	4.431
88	276.46	6082.12	7,744	681,472	9.380	4.447
89	279.60	6221.14	7,921	704,969	9.433	4.461
90	282.74	6361.73	8,100	729,000	9.486	4.481
91	285.88	6503.88	8,281	753,571	9.539	4.497
92	289.03	6647.61	8,464	778,688	9 591	4.514
93	292.17	6792.91	8,649	804,357	9.643	4.530
94	295.31	6939.78	8,836	830,584	9.695	4.546
95	298.45	7088.22	9,025	857,375	9.746	4.562
96	301.59	7238.23	9,216	884,736	9.797	4.578
97	304.73	7389.81	9,409	912,673	9.848	4.594
98	307.88	7542.96	9,604	941,192	9.899	4.610
99	311.02	7697.69	9,801	970,299	9.949	4.626
100	314.16	7853.98	10,000	1,000,000	10.000	4.641
101	317.30	8011.85	10,201	1,030,301	10.049	4.657
102	320.41	8171.28	10,404	1,061,208	10.099	4.672
103	323.58	8332.29	10,609	1,092,727	10.148	4.687
104	326.73	8494.87	10,816	1,124,864	10.198	4.702
105	329.87	8659.01	11,025	1,157,625	10.246	4.717
106	333.01	8824.73	11,236	1,191,016	10.295	4.732

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
107	336.15	8992.02	11,449	1,225,043	10.344	4.747
108	339.29	9160.88	11,664	1,259,712	10.392	4.762
109	342.43	9331.32	11,881	1,295,029	10.440	4.776
110	345.57	9503.32	12,100	1,331,000	10.488	4.791
111	348.72	9676.89	12,321	1,367,631	10.535	4.805
112	351.86	9852.03	12,544	1,404,928	10.583	4.820
113	355.00	10028.75	12,769	1,442,897	10.630	4.834
114	358.14	10207.03	12,996	1,481,544	10.677	4.848
115	361.28	10386.89	13,225	1,520,875	10.723	4.862
116	364.42	10568.32	13,456	1,560,896	10.770	4.876
117	367.57	10751.32	13,689	1,601,613	10.816	4.890
118	370.71	10935.88	13,924	1,643,032	10.862	4.904
119	373.85	11122.02	14,161	1,685,159	10.908	4.918
120	376.99	11309.73	14,400	1,728,000	10.954	4.932
121	380.13	11499.01	14,641	1,771,561	11.000	4.946
122	383.27	11689.87	14,884	1,815,848	11.045	4.959
123	386.42	11882.29	15,129	1,860,867	11.090	4.973
124	389.56	12076.28	15,376	1,906,624	11.135	4.986
125	392.70	12271.85	15,629	1,953,125	11.180	5.000
126	395.84	12468.98	15,876	2,000,376	11.224	5.013
127	398.98	12667.69	16,129	2,048,383	11.269	5.026
128	402.12	12867.96	16,384	2,097,152	11.313	5.039
129	405.26	13069.81	16,641	2,146,689	11.357	5.052
130	408.41	13273.23	16,900	2,197,000	11.401	5.065
131	411.55	13478.22	17,161	2,248,091	11.445	5.078
132	414.69	13684.78	17,424	2,299,968	11.489	5.091
133	417.83	13892.91	17,689	2,352,637	11.532	5.104
134	420.97	14102.61	17,956	2,406,104	11.575	5.117
135	424.11	14313.88	18,225	2,460,375	11.618	5.129
136	427.26	14526.72	18,496	2,515,456	11.661	5.142
137	430.40	14741.14	18,769	2,571,353	11.704	5.155
138	433.54	14957.12	19,044	2,620,872	11.747	5.167
139	436.68	15174 68	19,321	2,685,619	11 789	5.180
140	439.82	15393.80	19,600	2,744,000	11.832	5.192
141	442.96	15614.50	19,881	2,803,221	11 874	5.204
142	446.11	15836.77	20,164	2,863,288	11.916	5.217
143	449.25	16060.61	20,449	2,924,207	11.958	5.229
144	452.39	16286.02	20,736	2,985,984	12.000	5.241
145	455.53	16513.00	21,025	3,048,625	12.041	5.253
146	458.67	16741.55	21,316	3,112,136	12.083	5.265
147	461.81	16971.67	21,609	3,176,523	12.124	5.277
148	464.96	17203.36	21,904	3,241,792	12.165	5.289
149	468.10	17436.62	22,201	3,307,949	12 206	5.301
150	471.24	17671.46	22,500	3,375,000	12.247	5.313
151	474.38	17907.86	22,801	3,442,951	12.288	5.325
152	477.52	18145.84	23,104	3,511,808	12.328	5.336
153	480.66	18385.39	23,409	3,581,577	12.369	5.348
154	483.80	18626.50	23,716	3,652,264	12.409	5.360
155	486.95	18869.19	24,025	3,723,875	12.449	5.371
156	490.09	19113.45	24,336	3,796,416	12.489	5.383
157	493.23	19359.28	24,649	3,869,893	12 529	5.394
158	496.37	19606.68	24,964	3,944,312	12.569	5.406
159	499.51	19855.65	25,281	4,019,679	12.609	5.417
160	502.65	20106.19	25,600	4,096,000	12.649	5.428
161	505.80	20358.34	25,921	4,173,281	12.688	5.440
162	508.94	20611.99	26,244	4,251,528	12.727	5.451

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
163	512.08	20867.24	26,569	4,330,747	12.767	5.462
164	515.22	21124.07	26,896	4,410,944	12.806	5.473
165	518.36	21382.46	27,225	4,495,125	12.845	5.484
166	521.50	21642.43	27,556	4,574,296	12.884	5.495
167	524.65	21903.97	27,889	4,657,463	12.922	5.506
168	527.79	22167.08	28,224	4,741,632	12.961	5.517
169	530.93	22431.76	28,561	4,826,809	13.000	5.528
170	534.07	22698.01	28,900	4,913,000	13.038	5.539
171	537.21	22965.83	29,241	5,000,211	13.076	5.550
172	540.35	23235.22	29,584	5,088,448	13.114	5.561
173	543.50	23506.18	29,929	5,177,717	13.152	5.572
174	546.64	23778.71	30,276	5,268,024	13.190	5.582
175	549.78	24052.82	30,625	5,359,375	13.228	5.593
176	552.92	24328.49	30,976	5,451,776	13.266	5.604
177	556.06	24605.79	31,329	5,545,233	13.304	5.614
178	559.20	24884,56	31,684	5,639,752	13.341	5.625
179	562.34	25164.94	32,041	5,735,339	13.379	5.635
180	565.49	25446 90	32,400	5,832,000	13.416	5.646
181	568.63	25730.43	32,761	5,929,741	13.453	5.656
182	571.77	26015.53	33,124	6,028,568	13.490	5.667
183	574.91	26302.20	33,489	6,128,487	13.527	5.677
184	578.05	26590.44	33,856	6,229,504	13.564	5.687
185	581.19	26880.25	34,225	6,331,625	13.601	5.698
186	584.34	27171.63	34,596	6,434,856	13.638	5.708
187	587.48	27464.59	34,969	6,539,203	13.674	5.718
188	590.62	27759.11	35,344	6,644,672	13.711	5.728
189	593.76	28055.21	35,721	6,751,269	13.747	5.738
190	596.90	28352.87	36,100	6,859,000	13.784	5.748
191	600.04	28652.11	36,481	6,967,871	13.820	5.758
192	603.19	28952.92	36,864	7,077,888	13.856	5.768
193	606.33	29255.30	37,249	7,189,057	13.892	5.778
194	609.47	29559.26	37,636	7,301,384	13.928	5.788
195	612.61	29864.77	38,025	7,414,875	13.964	5.798
196	615.75	30171.86	38,416	7,529,536	14.000	5.808
197	618.89	30480.52	38,809	7,645,373	14.035	5.818
198	622.03	30790.75	39,204	7,762,392	14.071	5.828
199	625.18	31102.55	39,601	7,880,599	14.106	5.838
200	628.32	31415.93	40,000	8,000,000	14.142	5.848
201	631.46	31730.87	40,401	8,120,601	14.177	5.857
202	634.60	32047.39	40,804	8,242,408	14.212	5.867
203	637.74	32365.47	41,209	8,365,427	14.247	5.877
204	640.88	32685.13	41,616	8,489,664	14.282	5.886
205	644.03	33006.36	42,025	8,615,125	14.317	5.896
206	647.17	33329.16	42,436	8,741,816	14.352	5.905
207	650.31	33653.53	42,849	8,869,743	14.387	5.915
208	653.45	33979.47	43.264	8,998,912	14.422	5.924
209	656.59	34306.98	43,681	9,123,329	14.456	5.934
210	659.73	34636.06	44,100	9,261,000	14.491	5.943
211	662.88	34966.71	44,521	9,393,931	14.525	5.953
212	666.02	35298.94	44,944	9,528,128	14.560	5.962
213	669.16	35632.73	45,369	9,663,597	14.594	5.972
214	672.30	35968.09	45,796	9,800,344	14.628	5.981
215	675.44	36305.03	46,225	9,938,375	14.662	5.990
216	678.58	36643.61	46,656	10,077,696	14.696	6.000
217	681.73	36983.61	47,089	10,218,313	14.730	6.009
218	684.87	37325.26	47,524	10,360,232	14.764	6.018

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
219	688.01	37668.48	47,961	10,503,459	14.798	6.027
220	691.15	..38013.27	.. 48,400	..10,648,000	14.832	6.036
221	694.29	38359.63	48,841	10,793,861	14.866	6.045
222	697.43	..38707.56	.. 49,284	..10,941,048	14.899	6.055
223	700.57	39057.07	49,729	11,089,567	14.933	6.064
224	703.72	..39408.14	.. 50,176	..11,239,424	14.966	6.073
225	706.86	39760.78	50,625	11,390,625	15.000	6.082
226	710.00	..40115.00	.. 51,076	..11,543,176	15.033	6.091
227	713.14	40470.78	51,529	11,697,083	15.066	6.100
228	716.28	..40828.14	.. 51,984	..11,852,352	15.099	6.109
229	719.42	41187.07	52,441	12,008,989	15.132	6.118
230	722.57	..41547.56	.. 52,900	..12,167,000	15.165	6.126
231	725.71	41909.63	53,361	12,326,391	15.198	6.135
232	728.85	..42273.27	.. 53,824	..12,487,168	15.231	6.144
233	731.99	42638.48	54,289	12,649,337	15.264	6.153
234	735.13	..43005.26	.. 54,756	..12,812,904	15.297	6.162
235	738.27	43373.61	55,225	12,977,875	15.329	6.171
236	741.42	..43743.54	.. 55,696	..13,144,256	15.362	6.179
237	744.56	44115.03	56,169	13,312,053	15.394	6.188
238	747.70	..44488.09	.. 56,644	..13,481,272	15.427	6.197
239	750.84	44862.73	57,121	13,651,919	15.459	6.205
240	753.98	..45238.93	.. 57,600	..13,824,000	15.491	6.214
241	757.12	45616.71	58,081	13,997,521	15.524	6.223
242	760.26	..45996.06	.. 58,564	..14,172,488	15.556	6.231
243	763.41	46376.98	59,049	14,348,907	15.588	6.240
244	766.55	..46759.47	.. 59,536	..14,526,784	15.620	6.248
245	769.69	47143.52	60,025	14,706,125	15.652	6.257
246	772.83	..47529.16	.. 60,516	..14,886,936	15.684	6.265
247	775.97	47916.36	61,009	15,069,223	15.716	6.274
248	779.11	..48305.13	.. 61.504	..15,252,992	15.748	6.282
249	782.26	48695.47	62,001	15,438,249	15.779	6.291
250	785.40	..49087.39	.. 62,500	..15,625,000	15.811	6.299
251	788.54	49480.87	63,001	15,813,251	15.842	6.307
252	791.68	..49875.92	.. 63,504	..16,003,008	15.874	6.316
253	794.82	50272.55	64,009	16,194,277	15.905	6.324
254	797.96	..50670.75	.. 64,516	..16,387,064	15.937	6.333
255	801.11	51070.52	65,025	16,581,375	15.968	6.341
256	804.25	..51471.86	.. 65,536	..16,777,216	16.000	6.349
257	807.39	51874.76	66,049	16,974,593	16.031	6.357
258	810.53	..52279.24	.. 66,564	..17.173,512	16.062	6.366
259	813.67	52685.29	67,081	17,373,979	16.093	6.374
260	816.81	..53092.96	.. 67,600	..17,576,000	16.124	6.382
261	819.96	53502.11	68,121	17,779,581	16.155	6.390
262	823.10	..53912.87	.. 68,644	..17,984,728	16.186	6.398
263	826.24	54325.21	69,169	18,191,447	16.217	6.406
264	829.38	..54739.11	.. 69,696	..18,399,744	16.248	6.415
265	832.52	55154.59	70,225	18,609,625	16.278	6.423
266	835.66	..55571.63	.. 70,756	..18,821,096	16.309	6.431
267	838.80	55990.25	71,289	19,034,163	16.340	6.439
268	841.95	..56410.44	.. 71,824	..19,248,832	16.370	6.447
269	845.09	56832.20	72,361	19,465,109	16.401	6.455
270	848.23	..57255.53	.. 72,900	..19,683,000	16.431	6.463
271	851.37	57680.43	73,441	19,902,511	16.462	6.471
272	854.51	..58106.90	.. 73,984	..20,123,648	16.492	6.479
273	857.65	58534.94	74,529	20,346,417	16.522	6.487
274	860.89	..58964.55	.. 75,076	..20,570.824	16.552	6.495

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
275	863.94	59395.74	75,625	20,796,875	16.583	6.502
276	867.08	59828.49	76,176	21,024,576	16.613	6.510
277	870.22	60262.82	76,729	21,253,933	16.643	6.518
278	873.36	60698.72	77,284	21,484,952	16.673	6.526
279	876.50	61136.18	77,841	21,717,639	16.703	6.534
280	879.65	61575.22	78,400	21,952,000	16.733	6.542
281	882.79	62015.82	78,961	22,188,041	16.763	6,549
282	885.93	62458.00	79,524	22,425,768	16.792	6.557
283	889.07	62901.75	80,089	22,665,187	16.822	6.565
284	892.21	63347.07	80,656	22,906,304	16.852	6.573
285	895.35	63793.97	81,225	23,149,125	16.881	6.580
286	898.49	64242.43	81,796	23,393,656	16.911	6.588
287	901.64	64692.46	82,369	23,639,903	16.941	6.596
288	904.78	65144.07	82,944	23,887,872	16.970	6.603
289	907.92	65597.24	83,521	24,137,569	17.000	6.611
290	911.06	66051.99	84,100	24,389,000	17.029	6.619
291	914.20	66508.30	84,681	24,642,171	17.059	6.627
292	917.34	66966.19	85,264	24,897,088	17.088	6.634
293	920.49	67425.65	85,849	25,153,757	17.117	6.642
294	923.63	67886.68	86,436	25,412,184	17.146	6.649
295	926.77	68349.28	87,025	25,672,375	17.176	6.657
296	929.91	68813.45	87,616	25,934,336	17.205	6.664
297	933.05	69279.19	88,209	26,198,073	17.234	6.672
298	936.19	69746.50	88,804	26,463,592	17.263	6.679
299	939.34	70215.38	89,401	26,730,899	17.292	6.687
300	942.48	70685.83	90,000	27,000,000	17.320	6.694
301	945.62	71157.86	90,601	27,270,901	17.349	6.702
302	948.76	71631.45	91,204	27,543,608	17.378	6.709
303	951.90	72106.62	91,809	27,818,127	17.407	6.717
304	955.04	72583.36	92,416	28,094,464	17.436	6.724
305	958.19	73061.66	93,025	28,372,625	17.464	6.731
306	961.33	73541.54	93,636	28,652,616	17.493	6.739
307	964.47	74022.99	94,249	28,934,443	17.521	6.746
308	967.61	74506.01	94,864	29,218,112	17.549	6.753
309	970.75	74990.60	95,481	29,503,629	17.578	6.761
310	973.89	75476.76	96,100	29,791,000	17.607	6.768
311	977.03	75964.50	96,721	30,080,231	17.635	6.775
312	980.18	76453.80	97,344	30,371,328	17.663	6.782
313	983.32	76944.67	97,969	30,664,297	17.692	6.789
314	986.46	77437.12	98,596	30,959,144	17.720	6.797
315	989.60	77931.13	99,225	31,255,875	17.748	6.804
316	992.74	78426.72	99,856	31,554,496	17.776	6.811
317	995.88	78923.88	100,489	31,855.013	17.804	6.818
318	999.03	79422.60	101,124	32,157,432	17.832	6.826
319	1002.17	79922.90	101,761	32,461,759	17.860	6.833
320	1005.31	80424.77	102,400	32,768,000	17.888	6.839
321	1008.45	80928.21	103,041	33,076,161	17.916	6.847
322	1011.59	81433.22	103,684	33,386,248	17.944	6.854
323	1014.73	81939.80	104,329	33,698.267	17.972	6.861
324	1017.88	82447.96	104,976	34,012,224	18.000	6.868
325	1021.02	82957.68	105,625	34,328,125	18.028	6.875
326	1024.16	83468.98	106,276	34,645,976	18.055	6.882
327	1027.30	83981.84	106,929	34,965,783	18.083	6.889
328	1030.44	84496.28	107,584	35,287,552	18.111	6.896
329	1033.58	85012.28	108,241	35,611,289	18.138	6.903
330	1036.73	85529.86	108,900	35,937,000	18.166	6.910

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
331	1039.87	86049.01	109,561	36,264,691	18.193	6.917
332	1043.01	..86569.73	110,224	.. 36,594,368	18.221	6.924
333	1046.15	87092.02	110,889	36,926,037	18.248	6 931
334	1049.29	..87615.88	111,556	.. 37,259,704	18.276	6.938
335	1052.43	88141.31	112,225	37,595,375	18.303	6.945
336	1055.57	..88668.31	112,896	.. 37,933,056	18.330	6.952
337	1058.72	89196.88	113,569	38,272,753	18.357	6.959
338	1061.86	..89727.03	114,244	.. 38,614,472	18.385	6.966
339	1065.00	90258.74	114,921	38,958,219	18.412	6.973
340	1068.14	..90792.03	115,600	.. 39,304,000	18.439	6.979
341	1071.28	91326.88	116,281	39,651,821	18.466	6.986
342	1074.42	..91863.31	116,964	.. 40,001,688	18.493	6.993
343	1077.57	92401.31	117,649	40,353,607	18.520	7.000
344	1080.71	..92940.88	118,336	.. 40,707,584	18.547	7.007
345	1083.85	93482.02	119,025	41,063,625	18.574	7.014
346	1086.99	..94024.73	119,716	.. 41,421,736	18.601	7.020
347	1090.13	94569.01	120,409	41,781,923	18.628	7.027
348	1093.27	..95114.86	121,104	.. 42,144,192	18.655	7.034
349	1096.42	95662.28	121,801	42,508,549	18.681	7.040
350	1099.56	..96211.28	122,500	.. 42,875,000	18.708	7.047
351	1102.70	96761.84	123,201	43,243,551	18.735	7.054
352	1105.84	..97314.76	123,904	.. 43,614,208	18.762	7.061
353	1108.98	97867.68	124,609	43,986,977	18.788	7.067
354	1112.12	..98422.96	125,316	.. 44,361,864	18.815	7.074
355	1115.26	98979.80	126,025	44,738,875	18.842	7.081
356	1118.41	..99538.22	126,736	.. 45,118,016	18.868	7.087
357	1121.55	100098.21	127,449	45,499,293	18.894	7.094
358	1124.69	100659.27	128,164	.. 45,882,712	18.921	7.101
359	1127.83	101222.90	128,881	46,268,279	18.947	7.107
360	1130.97	101787.60	129,600	.. 46,656,000	18.974	7.114
361	1134.11	102353.87	130,321	47,045,881	19.000	7.120
362	1137.26	102921.72	131,044	.. 47,437,928	19.026	7.127
363	1140.40	103491.13	131,769	47,832,147	19.052	7.133
364	1143.54	104062.12	132,496	.. 48,228,544	19.079	7.140
365	1146.68	104634.67	133,225	48,627,125	19.105	7.146
366	1149.82	105208.80	133,956	.. 49,027,896	19.131	7.153
367	1152.96	105784.49	134,689	49,430,863	19.157	7.159
368	1156.11	106361.76	135,424	.. 49,836,032	19.183	7.166
369	1159.25	106940.60	136,161	50,243,409	19.209	7.172
370	1162.39	107521.01	136,900	.. 50,653,000	19.235	7.179
371	1165.53	108102.99	137,641	51,064,811	19.261	7.185
372	1168.67	108686.54	138,384	.. 51,478,848	19.287	7.192
373	1171.81	109271.66	139,129	51,895,117	19.313	7.198
374	1174.96	109858.35	139,876	.. 52,313,624	19.339	7.205
375	1178.10	110446.62	140,625	52,734,375	19.365	7.211
376	1181.24	111036.45	141,376	.. 53,157,376	19.391	7.218
377	1184.38	111627.86	142,129	53,582,633	19.416	7.224
378	1187.52	112220.83	142,884	.. 54,010,152	19.442	7.230
379	1190.66	112815.38	143,641	54,439,939	19.468	7.237
380	1193.80	113411.49	144,400	.. 54,872,000	19.493	7.243
381	1196.95	114009.18	145,161	55,306,341	19.519	7.249
382	1200.09	114608.44	145,924	.. 55,742,968	19.545	7.256
383	1203.23	115209.27	146,689	56,181,887	19.570	7.262
384	1206.37	115811.67	147,456	.. 56,623,104	19.596	7.268
385	1209.51	116415.64	148,225	57,066,625	19.621	7.275
386	1212.65	117021.18	148,996	.. 57,512,456	19.647	7.281

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
387	1215.80	117628.30	149.769	57,960,603	19.672	7.287
388	1218.94	118236.98	150.544	.. 58,411,072	19.698	7.294
389	1222.08	118847.24	151.321	58,863,869	19.723	7.299
390	1225.22	119459.06	152.100	.. 59,319,000	19.748	7.306
391	1228.36	120072.46	152.881	59,776,471	19.774	7.312
392	1231.50	120687.42	153.664	.. 60,236,288	19.799	7.319
393	1234.65	121303.96	154.449	60,698,457	19.824	7.325
394	1237.79	121922.07	155.236	.. 61,162,984	19.849	7,331
395	1240·93	122541.75	156.025	61,629,875	19.875	7.337
396	1244.07	123163.00	156.816	.. 62,099,136	19.899	7.343
397	1247.21	123785.82	157.609	62,570,773	19.925	7.349
398	1250.35	124410.21	158.404	.. 63,044,792	19.949	7.356
399	1253.49	125036.17	159.201	63,521,199	19.975	7.362
400	1256.64	125663.71	160.000	.. 64,000,000	20.000	7.368
401	1259.78	126292.81	160.801	64,481,201	20.025	7.374
402	1262.92	126923.48	161.604	.. 64,964,808	20.049	7.380
403	1266.06	127553.73	162.409	65,450,827	20.075	7.386
404	1269.20	128189.55	163.216	.. 65,939,264	20.099	7.392
405	1272.34	128824.93	164.025	66,430,125	20.125	7.399
406	1275.49	129461.89	164.836	.. 66,923,416	20.149	7.405
407	1278.63	130100.42	165.649	67,419,143	20.174	7.411
408	1281.77	130740.52	166.464	.. 67,911,312	20.199	7.417
409	1284.91	131382.19	167.281	68,417,929	20.224	7.422
410	1288.05	132025.43	168.100	.. 68,921,000	20.248	7.429
411	1291.19	132670.24	168.921	69,426,531	20.273	7.434
412	1294.34	133316.63	169.744	.. 69,934,528	20.298	7.441
413	1297.48	133964.58	170.569	70,444,997	20.322	7.447
414	1300.62	134614.10	171.396	.. 70,957,944	20.347	7.453
415	1303.76	135265.20	172.225	71,473,375	20.371	7.459
416	1306.90	135917.86	173.056	.. 71,991,296	20.396	7.465
417	1310.04	136572.10	173.889	72,511,713	20.421	7.471
418	1313.19	137227.91	174.724	.. 73,034,632	20.445	7.477
419	1316.33	137885.29	175.561	73,560,059	20.469	7.483
420	1319.47	138544.24	176.400	.. 74,088,000	20.494	7.489
421	1322.61	139204.70	177.241	74,618,461	20 518	7.495
422	1325.75	139866.85	178.084	.. 75,151,448	20.543	7.501
423	1328.89	140530.51	178.929	75,686,967,	20.567	7.507
424	1332.03	141195.74	179.776	.. 76,225,024	20.591	7.513
425	1335.18	141862.54	180.625	76,765,625	20.615	7.518
426	1338.32	142530.92	181.476	.. 77,308,776	20.639	7.524
427	1341.46	143200.86	182.329	77,854,483	20.664	7.530
428	1344.60	143872.38	183.184	.. 78,402,752	20.688	7.536
429	1347.74	144545.46	184.041	78,953,589	20.712	7.542
430	1350.88	145220.12	184.900	.. 79,507,000	20.736	7.548
431	1354.03	145896.35	185.761	80,062,991	20.760	7.554
432	1357.17	146574.15	186.624	.. 80,621,568	20.785	7.559
433	1360.31	147253.52	187.489	81,182,737	20.809	7.565
434	1363.45	147934.46	188.356	.. 81,746,504	20.833	7.571
435	1366.59	148616.97	189.225	82,312,875	20.857	7.577
436	1369.73	149301.05	190.096	.. 82,881,856	20 881	7.583
437	1372.88	149986.70	190.969	83,453,453	20.904	7.588
438	1376.02	150673.93	191.844	.. 84,027,672	20.928	7.594
439	1379.16	151362.72	192.721	84,604,519	20.952	7.600
440	1382.30	152053.08	193.600	.. 85,184,000	20.976	7.606
441	1385.44	152745.02	194.481	85,766,121	21.000	7.612
442	1388.58	153438.53	195.364	.. 86,350,388	21.024	7.617

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
443	1391.73	154133.60	196,249	86,938,307	21.047	7.623
444	1394.87	154830.25	197,136	..87,528,384	21.071	7.629
445	1398.01	155528.47	198,025	88,121,125	21.095	7.635
446	1401.15	156228.26	198,916	..88,716,536	21.119	7.640
447	1404.29	156929.62	199,809	89,314,623	21.142	7.646
448	1407.43	157632.55	200,704	..89,915,392	21.166	7.652
449	1410.57	158337.06	201,601	90,518,849	21.189	7.657
450	1413.72	159043.13	202,500	..91,125,000	21.213	7.663
451	1416.86	159750.77	203,401	91,733,851	21.237	7.669
452	1420.00	160459.99	204,304	..92,345,408	21.260	7.674
453	1423.14	161170.77	205,209	92,959,677	21.284	7.680
454	1426.28	161883.13	206,106	..93,576,664	21.307	7.686
455	1429.42	162597.06	207.025	94,196,375	21.331	7.691
456	1432.57	163312.55	207,936	..94,818,816	21.354	7.697
457	1435.71	164029.62	208,849	95,443,993	21.377	7.703
458	1438.85	164748.26	209,764	..96,071,912	21.401	7.708
459	1441.99	165468.47	210,681	96,702,579	21.424	7.714
460	1445.13	166190.25	211,600	..97,336,000	21.447	7.719
461	1448.27	166913.60	212,521	97,972,181	21.471	7.725
462	1451.42	167638.53	213,444	..98,611,128	21.494	7.731
463	1454.56	168365.02	214,369	99,252,847	21.517	7.736
464	1457.70	169093.08	215,296	..99,897,345	21.541	7.742
465	1460.84	169822.72	216,225	100,544,625	21.564	7.747
466	1463.98	170553.92	217,156	101,194,696	21.587	7.753
467	1467.12	171286.70	218,089	101,847,563	21.610	7.758
468	1470.26	172021.05	219,024	102,503,232	21.633	7.764
469	1473.41	172756.97	219,961	103,161,709	21.656	7.769
470	1476.55	173494.45	220,900	103,823,000	21.679	7.775
471	1479.69	174233.51	221,841	104,487,111	21.702	7.780
472	1482.83	174974.14	222,784	105,154,048	21.725	7.786
473	1485.97	175716.35	223,729	105,823,817	21.749	7.791
474	1489.11	176460.12	224,676	106,496,424	21.771	7.797
475	1492.26	177205.46	225,625	107,171,875	21.794	7.802
476	1495.40	177952.37	226,576	107,850,176	21.817	7.808
477	1498.54	178700.86	227,529	108,531,333	21.840	7.813
478	1501.68	179450.91	228,484	109,215,352	21.863	7.819
479	1504.82	180202.54	229,441	109,902,239	21.886	7.824
480	1507.96	180955.74	230,400	110,592,000	21.909	7.830
481	1511.11	181710.50	231,361	111,284,641	21.932	7.835
482	1514.25	182466.84	232,324	111,980,168	21.954	7.840
483	1517.39	183224.75	233,289	112,678,587	21.977	7.846
484	1520.53	183984.23	234,256	113,379,904	22.000	7.851
485	1523.67	184745.28	235,225	114,084,125	22.023	7.857
486	1526.81	185507.90	236,196	114,791,256	22.045	7.862
487	1529.96	186272.10	237,169	115,501,303	22.069	7.868
488	1533.10	187037.86	238,144	116,214,272	22.091	7.873
489	1536.24	187805.19	239,121	116,936,169	22.113	7.878
490	1539.38	188574.10	240,100	117,649,000	22.136	7.884
491	1542.52	189344.57	241,081	118,370,771	22.158	7.889
492	1545.66	190116.62	242.064	119,095,488	22.181	7.894
493	1548.80	190890.24	243,049	119,823,157	22.204	7.899
494	1551.95	191665.43	244,036	120,553,784	22.226	7.905
495	1555.09	192442.19	245,025	121,287,375	22.248	7.910
496	1558.23	193220.51	246,016	122,023,936	22.271	7.915
497	1561.37	194000.42	247,009	122,763,473	22.293	7.921
498	1564.51	194781.89	248,004	123,505,992	22.316	7.926

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
499	1567.65	195564.93	249,001	124,251,499	22.338	7.932
500	1570.80	196349.54	250,000	125,000,000	22.361	7.937
501	1573.94	197135.72	251,001	125,751,501	22.383	7.942
502	1577.08	197923.48	252,004	126,506,008	22.405	7.947
503	1580.22	198712.80	253,009	127,263,527	22.428	7.953
504	1583.36	199503.70	254,016	128,024,864	22.449	7.958
505	1586.50	200296.17	255,025	128,787,625	22.472	7.963
506	1589.65	201090.20	256,036	129,554,216	22.494	7.969
507	1592.79	201885.81	257,049	130,323,843	22.517	7.974
508	1595.93	202682.99	258,064	131,096,512	22.539	7.979
509	1599.07	203481.74	259,081	131,872,229	22.561	7.984
510	1602.21	204282.06	260,100	132,651,000	22.583	7.989
511	1605.35	205083.95	261,121	133,432,831	22.605	7.995
512	1608.49	205887.42	262,144	134,217,728	22.627	8.000
513	1611.64	206692.45	263,169	135,005,697	22.649	8.005
514	1614.78	207499.05	264,196	135,796,744	22.671	8.010
515	1617.92	208307.23	265,225	136,590,875	22.694	8.016
516	1621.06	209116.97	266,256	137,388,096	22.716	8.021
517	1624.20	209928.29	267,289	138,188,413	22.738	8.026
518	1627.34	210741.18	268,324	138,991,832	22.759	8.031
519	1630.49	211555.63	269,361	139,798,359	22.782	8.036
520	1633.63	212371.66	270,400	140,608,000	22.803	8.041
521	1636.77	213189.26	271,441	141,420,761	22.825	8.047
522	1639.91	214008.43	272,484	142,236,648	22.847	8.052
523	1643.05	214829.17	273,529	145,055,667	22.869	8.057
524	1646.19	215651.49	274,576	143,877,824	22.891	8.062
525	1649.34	216475.37	275,625	144,703,125	22.913	8.067
526	1652.48	217300.82	276,676	145,531,576	22.935	8.072
527	1655.62	218127.85	277,729	146,363,183	22.956	8.077
528	1658.76	218956.44	278,784	147,197,952	22.978	8.082
529	1661.90	219786.61	279,841	148,035,889	23.000	8.087
530	1665.04	220618.32	280,900	148,877,000	23.022	8.093
531	1668.19	221451 65	281,961	149,721,291	23.043	8.098
532	1671.33	222286.53	283,024	150,568,768	23.065	8.103
533	1674.47	223122.98	284,089	151,419,437	23.087	8.108
534	1677.61	223961.00	285,156	152,273,304	23.108	8.113
535	1680.75	224800.59	286,225	153,130,375	23.130	8.118
536	1683.89	225641.75	287,296	153,990,656	23.152	8.123
537	1687.04	226484.48	288,369	154,854,153	23.173	8.128
538	1690.18	227328.77	289,444	155,720,872	23.195	8.133
539	1693.32	228174.66	290,521	156,590,819	23.216	8.138
540	1696.46	229022.10	291,600	157,464,000	23.238	8.143
541	1699.60	229871.12	292,681	158,340,421	23.259	8.148
542	1702.74	230721.71	293,764	159,220,088	23.281	8.153
543	1705.88	231573.86	294,849	160,103,007	23.302	8.158
544	1709.03	232427.59	295,936	160,989,184	23.324	8.163
545	1712.17	233282.89	297,025	161,878,625	23.345	8.168
546	1715.31	234139.76	298,116	162,771,336	23.367	8.173
547	1718.45	234998.20	299,209	163,667,323	23.388	8.178
548	1721.59	235858.21	300,304	164,566,592	23.409	8.183
549	1724.73	236719.79	301,401	165,469,149	23.431	8.188
550	1727.88	237582.94	302,500	166,375,000	23.452	8.193
551	1731.02	238447.67	303,601	167,281,151	23.473	8.198
552	1734.16	239313.96	304,704	168,196,608	23.495	8.203
553	1737.30	240181.83	305,809	169,112,377	23.516	8.208
554	1740.44	241051.26	306,916	170,031,464	23.537	8.213

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
555	1743.58	241922.27	308,025	170,953,875	23.558	8.218
556	1746.73	242794.85	309,136	171,879,616	23.579	8.223
557	1749.87	243668.99	310,249	172,808,693	23.601	8.228
558	1753.00	244544.61	311,364	173,741,112	23.622	8.233
559	1756.15	245422.00	312,481	174,676,879	23.643	8.238
560	1759.29	246300.86	313,600	175,616,000	23.664	8.242
561	1762.43	247181.30	314,721	176,558,481	23.685	8.247
562	1765.57	248062.30	315,844	177,504,328	23.706	8.252
563	1768.72	248946.87	316,969	178,453,547	23.728	8.257
564	1771.86	249832.01	318,096	179,406,144	23.749	8.262
565	1775.00	250718.73	319,225	180,362,125	23.769	8.267
566	1778.14	251607.01	320,356	181,321,496	23.791	8.272
567	1781.28	252496.87	321,489	182,284,263	23.812	8.277
568	1784.42	253388.30	322,624	183,250,432	23.833	8.282
569	1787.57	254281.30	323,761	184,220,009	23.854	8 286
570	1790.71	255175.86	324,900	185,193,000	23.875	8.291
571	1793.85	256072.00	326,041	186,169,411	23.896	8.296
572	1796.99	256969.71	327,184	187,149,248	23.916	8.301
573	1800.13	257868.99	328,329	188,132,517	23.937	8.306
574	1803.27	258769.85	329,476	189,119,224	23.958	8.311
575	1806.42	259672.27	330,625	190,109,375	23.979	8.315
576	1809.56	260576.26	331,776	191,102,976	24.000	8.320
577	1812.70	261481.83	332,929	192,100,033	24.021	8.325
578	1815.84	262388.96	334,084	193,100,552	24.042	8.330
579	1818.98	263297.67	335,241	194,104,539	24.062	8.335
580	1822.12	264207.94	336,400	195,112,000	24.083	8.339
581	1825.26	265119.79	337,561	196,122,941	24.104	8.344
582	1828.41	266033.21	338,724	197,137,368	24.125	8.349
583	1831.55	266948.20	339,889	198,155,287	24.145	8.354
584	1834.69	267864.76	341,056	199,176,704	24.166	8.359
585	1837.83	268782.80	342,225	200,201,625	24.187	8.363
586	1840.97	269702.59	343,396	201,230,056	24.207	8.368
587	1844.11	270623.86	344,569	202,262,003	24.228	8.373
588	1847.26	271546.70	345,744	203,297,472	24.249	8.378
589	1850.40	272471.12	346,921	204,336,469	24.269	8.382
590	1853.54	273397.10	348,100	205,379,000	24.289	8.387
591	1856.68	274324.66	349,281	206,425,071	24.310	8.392
592	1859.82	275253.78	350,464	207.474,688	24.331	8.397
593	1862.96	276184.48	351,649	208,527,857	24.351	8.401
594	1866.11	277116.75	352,836	209,584,584	24.372	8.406
595	1869.25	278050.59	354,025	210,644,875	24.393	8.411
596	1872.39	278985.99	355,216	211,708,736	24.413	8.415
597	1875.53	279922.97	356,409	212,776,173	24.433	8.420
598	1878.67	280861.53	357,604	213,847,192	24.454	8.425
599	1881.81	281801.65	358,801	214,921,799	24.474	8.429
600	1884.96	282743.34	360,000	216,000,000	24.495	8.434
601	1888.10	283686.60	361,201	217,081,801	24.515	8.439
602	1891.24	284631.44	362,404	218,167,208	24.536	8.444
603	1894.38	285577.84	363,609	219,256,227	24.556	8.448
604	1897.52	286525.82	364,816	220,348,864	24 576	8.453
605	1900.66	287475.36	366,025	221,445,125	24.597	8.458
606	1903.80	288426.48	367,236	222,545;016	24.617	8.462
607	1906.95	289379.17	368,449	223,648,543	24.637	8.467
608	1910.09	290333.43	369,664	224,755,712	24.658	8.472
609	1913.23	291289.26	370,881	225,866,529	24.678	8.476
610	1916.37	292246.66	372,100	226,981,000	24 698	8.481

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
611	1919.51	293205.63	373,321	228,099,131	24.718	8.485
612	1922.65	294166.17	374,544	229,220,928	24.739	8.490
613	1925.80	295128.28	375,769	230,346,397	24.758	8.495
614	1928.94	296091.97	376,996	231,475,544	24.779	8.499
615	1932.08	297057.22	378,225	232,608,575	24.799	8.504
616	1935.22	298024.05	379,456	233,744,896	24.819	8.509
617	1938.36	298992.44	380,689	234,885,113	24.839	8.513
618	1941.50	299962.41	381,924	236,029,032	24.859	8.518
619	1944.65	300933.95	383,161	237,176,659	24.879	8.522
620	1947.79	301907.05	384,400	238,628,000	24.899	8.527
621	1950.93	302881.73	385,641	239,483,061	24.919	8.532
622	1954.07	303857.98	386,884	240,641,848	24.939	8.536
623	1957.21	304835.80	388,129	241,804,367	24.959	8.541
624	1960.35	305815.20	389,376	242,970,624	24.980	8.545
625	1963.50	306796.16	390,625	244,140,625	25.000	8.549
626	1966.64	307778.69	391,876	245,314,376	25.019	8.554
627	1969.78	308762.79	393,129	246,491,883	25.040	8.559
628	1972.92	309748.47	394,384	247,673,152	25.059	8.563
629	1976.06	310735.71	395,641	248,858,189	25.079	8.568
630	1979.20	311724.53	396,900	250,047,000	25.099	8.573
631	1982.34	312714.92	398,161	251,239,591	25.119	8.577
632	1985.49	313706.88	399,424	252,435,968	25.139	8.582
633	1988.63	314700.40	400,689	253,636,137	25.159	8.586
634	1991.77	315695.50	401,956	254,840,104	25.179	8.591
635	1994.91	316692.17	403,225	256,047,875	25.199	8.595
636	1998.05	317690.42	404,496	257,259,456	25.219	8.599
637	2001.19	318690.23	405,769	258,474,853	25.239	8.604
638	2004.34	319691.61	407,044	259,694,072	25.259	8.609
639	2007.48	320694.56	408,321	260,917,119	25.278	8.613
640	2010.62	321699.09	409,600	262'144,000	25.298	8.618
641	2013.76	322705.18	410,881	263,374,721	25.318	8.622
642	2016.90	323712.85	412,164	264,609,288	25.338	8.627
643	2020.04	324722.09	413,449	265,847,707	25.357	8.631
644	2023.19	325732.89	414,736	267,089,984	25.377	8.636
645	2026.33	326745.27	416,025	268,836,125	25.397	8.640
646	2029.47	327759.22	417,316	269,586,136	25.416	8.644
647	2032.61	328774.74	418,609	270,840,023	25.436	8.649
648	2035.75	329791.83	419,904	272,097,792	25.456	8.653
649	2038.89	330810.49	421,201	273,359,449	25.475	8.658
650	2042.04	331830.72	422,500	274,625,000	25.495	8.662
651	2045.18	332852.53	423,801	275,894,451	25.515	8.667
652	2048.32	333875.90	425,104	277,167,808	25.534	8.671
653	2051.46	334900.85	426,409	278,445,077	25.554	8.676
654	2054.60	335927.36	427,716	279,726,264	25.573	8.680
655	2057.74	336955.45	429,025	281,011,375	25.593	8.684
656	2060.88	337985.10	430,336	282,800,416	25.612	8.689
657	2064.03	339016.33	431,649	283,593,393	25.632	8.693
658	2067.17	340049.13	432,964	284,890,312	25.651	8.698
659	2070.31	341083.50	434,281	286,191,179	25.671	8.702
660	2073.45	342119.44	435,600	287,496,000	25.690	8.706
661	2076.59	343156.95	436,921	288,804,781	25.710	8.711
662	2079.73	344196.03	438,244	290,117,528	25.720	8.715
663	2082.88	345236.69	439,569	291,434,247	25.749	8.719
664	2086.02	346278.91	440,896	292,754,944	25.768	8.724
665	2089.16	347322.70	442,225	294,079,625	25.787	8.728
666	2092.30	348368.07	443.556	295,408,296	25.807	8.733

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
667	2095.44	349415.00	444,889	296,740,963	25.826	8.737
668	2098.58	350463.51	446,224	298,077,632	25.846	8.742
669	2101.73	351513.59	447,561	299,418,309	25.865	8.746
670	2104.87	352565.24	448,900	300,763,000	25.884	8.750
671	2108.01	353618.43	450,241	302,111,711	25.904	8.753
672	2111.15	354673.24	451,584	303,464,448	25.923	8.759
673	2114.29	355729.60	452,929	304,821,217	25.942	8.763
674	2117.43	356787.54	454,276	306,182,024	25.961	8.768
675	2120.58	357847.04	455,625	307,546,875	25.981	8.772
676	2123.72	358908.11	456,976	308,915,776	26.000	8.776
677	2126.86	359970.75	458,329	310,288,733	26.019	8.781
678	2130.00	361034.97	459,684	311,665,752	26.038	8.785
679	2133.14	362100.75	461,041	313,046,839	26.058	8.789
680	2136.28	363168.11	462,400	314,432,000	26.077	8.794
681	2139.42	364237.04	463,761	315,821,241	26.096	8.798
682	2142.57	365307.54	465,124	317,214,568	26.115	8.802
683	2145.71	366379.60	466,489	318,611,987	26.134	8.807
684	2148.85	367453.24	467,856	320,013,504	26.153	8.811
685	2151.99	368528.45	469,225	321,419,125	26.172	8.815
686	2155.13	369605.23	470,596	322,828.856	26.192	8.819
687	2158.27	370683.59	471,969	324,242,703	26.211	8.824
688	2161.42	371763.51	473,344	325,660,672	26.229	8.828
689	2164.56	372845.00	474,721	327.082,769	26.249	8.832
690	2167.70	373928.07	476,100	328,509,000	26.268	8.836
691	2170.84	375012.70	477,481	329,939,371	26.287	8.841
692	2173.98	376098.91	478,864	331,373,888	26.306	8.845
693	2177.12	377186.68	480,249	332,812,557	26.325	8.849
694	2180.27	378276.03	481,636	334,255,384	26.344	8.853
695	2183.41	379366.95	483,025	335,702,375	26.363	8.858
696	2186.55	380459.44	484,416	337,153,536	26.382	8.862
697	2189.69	381553.50	485,809	338,608,873	26.401	8.866
698	2192.83	382649.43	487,204	340,068,392	26.419	8.870
699	2195.97	383746.33	488,601	341,532,099	26.439	8.875
700	2199.12	384845.10	490.000	343,000.000	26.457	8.879
701	2202.26	385945.44	491,401	344,472,101	26.476	8.883
702	2205.40	387047.36	492,804	345,948,088	26.495	8.887
703	2208.54	388150.84	494,209	347,428,927	26.514	8.892
704	2211.68	389255.90	495,616	348,913.664	26.533	8.896
705	2214.82	390362.52	497,025	350,402,625	26.552	8.900
706	2217.96	391470.32	498,436	351,895,816	26.571	8.904
707	2221.11	392580.49	499,849	353,393,243	26.589	8.908
708	2224.25	393691.83	501,264	354,894,912	26.608	8.913
709	2227.39	394804.74	502,681	356,400,829	26.627	8.917
710	2230.53	395919.21	504,100	357,911,000	26.644	8.921
711	2233.67	397035.27	505,521	359,425,431	26.664	8.925
712	2236.81	398152.89	506,944	360,944,128	26.683	8.929
713	2239.96	399272.08	508,369	362,467,097	26.702	8.934
714	2243.10	400392.84	509,796	363,994,344	26.721	8.938
715	2246.24	401515.18	511,225	365,525,875	26.739	8.942
716	2249.38	402639.08	512,656	367,061,696	26.758	8.946
717	2252.52	403764.56	514,089	368.601,813	26.777	8.950
718	2255.66	404891.60	515,524	370,146,232	26.795	8.954
719	2258.81	406020.22	516,961	371,694,959	26.814	8.959
720	2261.95	407150.41	518,400	373,248,000	26.833	8.963
721	2265.09	408282.17	519,841	374,805,361	26.851	8.967
722	2268.23	409415.50	521,284	376,367,048	26.870	8.971

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
723	2271.37	410550.40	522,729	377,933,067	26.889	8.975
724	2274.51	411686.87	524,126	379,503,424	26.907	8.979
725	2277.66	412824.91	525,625	381,078,125	26.926	8.983
726	2280.80	413964.52	527,076	382,657,176	26.944	8.988
727	2283.94	415105.71	528,529	384,240,583	26.963	8.992
728	2287.08	416248.46	529,984	385,828,352	26.991	8.996
729	2290.22	417392.79	531,441	387,420,489	27.000	9.000
730	2293.36	418538.68	532,900	389,017,000	27.018	9.004
731	2296.50	419686.15	534,361	390,617,891	27.037	9.008
732	2299.65	420835.19	535,824	392,223,168	27.055	9.012
733	2302.79	421985.79	537,289	393,832,837	27.074	9.016
734	2305.93	423137.97	538,756	395,446,904	27.092	9.020
735	2309.07	424291.72	540,225	397,065,375	27.111	9.023
736	2312.21	425447.04	541,696	398,688,256	27.129	9.029
737	2315.35	426603.93	543,169	400,315,553	27.148	9.033
738	2318.50	427762.40	544,644	401,947,272	27.166	9.037
739	2321.64	428922.43	546,121	403,583,419	27.184	9.041
740	2324.78	430084.03	547,600	405,224,000	27.203	9.045
741	2327.92	431247.21	549,081	406,869,021	27.221	9.049
742	2331.06	432411.95	550,564	408,518,488	27.239	9.053
743	2334.20	433578.27	552,049	410,172,407	27.258	9.057
744	2337.35	434746.16	553,536	411,830,784	27.276	9.061
745	2340.49	435915.62	555,025	413,493,625	27.295	9.065
746	2343.63	437086.64	556,516	415,160,936	27.313	9.069
747	2346.77	438259.24	558,009	416,832,723	27.331	9.073
748	2349.91	439433.41	559,504	418,508,992	27.349	9.077
749	2353.05	440609.16	561,001	420,189,749	27.368	9.081
750	2356.20	441786.47	562,500	421,875,000	27.386	9.086
751	2359.34	442965.35	564,001	423,564,751	27.404	9.089
752	2362.48	444145.80	565,504	424,525,900	27.423	9.094
753	2365.62	445327.83	567,009	426,957,777	27.441	9.098
754	2368.76	446511.42	568,516	428,661,064	27.459	9.102
755	2371.90	447696.59	570,025	430,368,875	27.477	9.106
756	2375.04	448883.32	571,536	432,081,216	27.495	9.109
757	2378.19	450071.63	573,049	433,798,093	27.514	9.114
758	2381.33	451261.51	574,564	435,519,512	27.532	9.118
759	2384.47	452452.96	576,081	437,245,479	27.549	9.122
760	2387.61	453645.98	577,600	438,976,000	27.568	9.126
761	2390.75	454840.57	579,121	440,711,081	27.586	9.129
762	2393.89	456036.73	580,644	442,450,728	27.604	9.134
763	2397.04	457234.46	582,169	444,194,947	27.622	9.138
764	2400.18	458433.77	583,696	445,943,744	27.640	9.142
765	2403.32	459634.64	585,225	447,697,125	27.659	9.146
766	2406.46	460837.08	586,756	449,455,096	27.677	9.149
767	2409.60	462041.10	588,289	451,217,663	27.695	9.154
768	2412.74	463246.69	589,824	452,984,832	27.713	9.158
769	2415.89	464453.84	591,361	454,756,609	27.731	9.162
770	2419.03	465662.57	592,900	456,533,000	27.749	9.166
771	2422.17	466872.87	594,441	458,314,011	27.767	9.169
772	2425.31	468084.74	595,984	460,099,648	27.785	9.173
773	2428.45	469298.18	597,529	461,889,917	27.803	9.177
774	2431.59	470513.19	599,076	463,684,824	27.821	9.181
775	2434.73	471729.77	600,625	465,484,375	27.839	9.185
776	2437.88	472947.92	602,176	467,288,576	27.857	9.189
777	2441.02	474167.65	603,729	469,097,433	27.875	9.193
778	2444.16	475388.94	605,284	470,910,952	27.893	9.197

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
779	2447.30	476611.81	606,841	472,729,139	27.910	9.201
780	2450.44	477836.24	608,400	474,552,000	27.928	9.205
781	2453.58	479062.25	609,961	476,379,541	27.946	9.209
782	2456.73	480289.83	611,524	478,211,768	27.964	9.213
783	2459.87	481518.97	613,089	480,048,687	27.982	9.217
784	2463.01	482749.69	614,656	481,890,304	28.000	9.221
785	2466.15	483981.98	616,225	483,736,025	28.017	9.225
786	2469.29	485215.84	617,796	485,587,656	28.036	9.229
787	2472.43	486451.28	619,369	487,443,403	28.053	9.233
788	2475.58	487688.28	620,944	489,303,872	28.071	9.237
789	2478.72	488926.85	622,521	491,169,069	28.089	9.240
790	2481.86	490166.99	624,100	493,039,000	28.107	9.244
791	2485.00	491408.71	625,681	494,913,671	28.125	9.248
792	2488.14	492651.99	627,264	496,793,088	28.142	9.252
793	2491.28	493896.85	628,849	498,677,257	28.160	9.256
794	2494.43	495143.28	630,436	500,566,184	28.178	9.260
795	2497.57	496391.27	632,025	502,459,875	28.196	9.264
796	2500.71	497640.84	633,616	504,358,336	28.213	9.268
797	2503.85	498891.98	635,209	506,261,573	28.231	9.271
798	2506.99	500144.69	636,804	508,169,592	28.249	9.275
799	2510.13	501398.97	638,401	510,082,399	28.266	9.279
800	2513.27	502654.82	640,000	512,000,000	28.284	9.283
801	2516.42	503912.25	641,601	513,922,401	28.302	9.287
802	2519.56	505171.24	643,204	515,849,608	28.319	9.291
803	2522.70	506431.80	644,809	517,781,627	28.337	9.295
804	2525.84	507693.94	646,416	519,718,464	28.355	9.299
805	2528.98	508957.65	648,025	521,660,125	28.372	9.302
806	2532.12	510222.92	649,636	523,606,616	28.390	9.306
807	2535.27	511489.77	651,249	525,557,943	28.408	9.310
808	2538.41	512758.19	652,864	527,514,112	28.425	9.314
809	2541.55	514028.19	654,481	529,474,129	28.443	9.318
810	2544.09	515299.74	656,100	531,441,000	28.460	9.321
811	2547.83	516572.86	657,721	533,411,731	28.478	9.325
812	2550.97	517847.57	659,344	535,387,328	28.496	9.329
813	2554.12	519123.84	660,969	537,366,797	28.513	9.333
814	2557.26	520401.68	662,596	539,353,144	28.531	9.337
815	2560.40	521681.10	664,225	541,343,375	28.548	9.341
816	2563.54	522962.08	665,856	543,338,496	28.566	9.345
817	2566.68	524244.63	667,489	545,338,513	28.583	9.348
818	2569.82	525528.76	669,124	547,343,432	28.601	9.352
819	2572.96	526814.46	670,761	549,353,259	28.618	9.356
820	2576.11	528101.73	672,400	551,368,000	28.636	9.360
821	2579.25	529390.56	674,041	553,387,661	28.653	9.364
822	2582.39	530680.97	675,684	555,412,248	28.670	9.367
823	2585.53	531972.95	677,329	557,441,767	28.688	9.371
824	2588.67	533266.50	678,976	559,476,224	28.705	9.375
825	2591.81	534561.63	680,625	561,515,625	28.723	9.379
826	2594.96	535858.32	682,276	563,559,976	28.740	9.383
827	2598.10	537156.58	683,929	565,609,283	28.758	9.386
828	2601.24	538456.41	685,584	567,663,552	28.775	9.390
829	2604.38	539757.82	687,241	569,722,789	28.792	9.394
830	2607.52	541060.79	688,900	571,787,000	28.810	9.398
831	2610.66	542365.34	690,561	573,856,191	28.827	9.401
832	2613.81	543671.46	692,224	575,930,368	28.844	9.405
833	2616.95	544979.15	693,889	578,009,537	28.862	9.409
834	2620.09	546288.40	695,556	580,093,704	28.879	9.413

Number, or Diameter.	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
835	2623.23	547599.23	697,225	582,182,875	28.896	9.417
836	2626.37	548911.63	698,896	584,277,056	28.914	9.420
837	2629.51	550225.61	700,569	586,376,253	28.931	9.424
838	2632.64	551541.15	702,244	588,480,472	28.948	9.428
839	2635.80	552858.26	703,921	590,589,719	28.965	9.432
840	2638.94	554176.94	705,600	592,704,000	28.983	9.435
841	2642.08	555497.20	707,281	594,823,321	29.000	9.439
842	2645.22	556819.02	708,964	596,947,688	29.017	9.443
843	2648.36	558142.42	710,649	599,077,107	29.034	9.447
844	2651.50	559467.39	712,336	601,211,584	29.052	9.450
845	2654.65	560793.92	714,025	603,351,125	29.069	9.454
846	2657.79	562122.03	715,716	605,495,736	29.086	9.458
847	2660.93	563451.71	717,409	607,645,423	29.103	9.461
848	2664.07	564782.96	719,104	609,800,192	29.120	9.465
849	2667.21	566115.78	720,801	611,960,049	29.138	9.469
850	2670.35	567450.17	722,500	614,125,000	29.155	9.473
851	2673.50	568786.14	724,201	616,295,051	29.172	9.476
852	2676.64	570123.67	725,904	618,470,208	29.189	9.480
853	2679.78	571462.77	727,609	620,650,477	29.206	9.483
854	2682.92	572803.45	729,316	622,835,864	29.223	9.487
855	2686.06	574145.69	731,025	625,026,375	29.240	9.491
856	2689.20	575489.51	732,736	627,222,016	29.257	9.495
857	2692.35	576834.90	734,449	629,422,793	29.274	9.499
858	2695.49	578181.85	736,164	631,628,712	29.292	9.502
859	2698.63	579530.38	737,881	633,839,779	29.309	9.506
860	2701.77	580880.48	739,600	636,056,000	29.326	9.509
861	2704.91	582232.15	741,321	638,277,381	29.343	9.513
862	2708.05	583585.39	743,044	640,503,928	29.360	9.517
863	2711.19	584940.21	744,769	642,735,647	29.377	9.520
864	2714.34	586296.59	746,496	644,972,544	29.394	9.524
865	2717.45	587654.54	748,225	647,214,625	29.411	9.528
866	2720.62	589014.07	749,956	649,461,896	29.428	9.532
867	2723.76	590375.16	751,689	651,714,363	29.445	9.535
868	2726.90	591737.83	753,424	653,972,032	29.462	9.539
869	2730.04	593102.06	755,161	656,234,909	29.479	9.543
870	2733.19	594467.87	756,900	658,503,000	29.496	9.546
871	2736.33	595835.25	758,641	660,776,311	29.513	9.550
872	2739.47	597204.20	760,384	663,054,848	29.529	9.554
873	2742.61	598574.72	762,129	665,338,617	29.546	9.557
874	2745.75	599946.81	763,876	667,627,624	29.563	9.561
875	2748.89	601320.47	765,625	669,921,875	29.580	9.565
876	2752.04	602695.70	767,376	672,221,376	29.597	9.568
877	2755.18	604072.50	769,129	674,526,133	29.614	9.572
878	2758.32	605450.88	770,884	676,836,152	29.631	9.575
879	2761.46	606830.82	772,641	679,151,439	29.648	9.579
880	2764.60	608212.34	774,400	681,472,000	29.665	9.583
881	2767.74	609595.42	776,161	683,797,841	29.682	9.586
882	2770.89	610980.08	777,924	686,128,968	29.698	9.590
883	2774.03	612366.31	779,689	688,465,387	29.715	9.594
884	2777.17	613754.11	781,456	690,807,104	29.732	9.597
885	2780.31	615143.48	783,225	693,154,125	29.749	9.601
886	2783.45	616534.42	784,996	695,506,456	29.766	9.604
887	2786.59	617926.93	786,769	697,864,103	29.782	9.608
888	2789.73	619321.01	788,544	700,227,072	29.799	9.612
889	2792.88	620716.66	790,321	702,595,369	29.816	9.615
890	2796.02	622113.89	792,100	704,969,000	29.833	9.619

Number, or Diameter	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
891	2799.16	623512.68	793,881	707,347,971	29.850	9.623
892	2802.30	624913.04	795,664	709,732,288	29.866	9.626
893	2805.44	626314.98	797,449	712,121,957	29.883	9.630
894	2808.58	627718.49	799,236	714,516,984	29.900	9.633
895	2811.73	629123.56	801,025	716,917,375	29,916	9.637
896	2814.87	630530.21	802,816	719,323,136	29.933	9.640
897	2818.01	631938.43	804.609	721,734,273	29.950	9.644
898	2821.15	633348·22	806,404	724,150,792	29.967	9.648
899	2824.29	634759.58	808,201	726,572,699	29.983	9.651
900	2827.43	636172.51	810,000	729,000,000	30.000	9.655
901	2830.58	637587 01	811,804	721,432,701	30.017	9.658
902	2833.72	639003.09	813,604	733,870,808	30.033	9.662
903	2836.86	640420.73	815,409	736,314,327	30.050	9.666
904	2840.00	641839.95	817,216	738,763,264	30.066	9.669
905	2843.14	643260.73	819,025	741,217,625	30.083	9.673
906	2846.28	644683 .09	820,836	743,677,416	30.100	9.676
907	2849 43	646107.01	822,614	746,142,643	30.116	9.680
908	2852.57	647532.51	824,464	748,613,312	30.133	9.683
909	2855.71	648959.58	826,281	751,089,429	30.150	9.687
910	2858.85	650388.21	828,100	753,571,000	30.163	9.690
911	2861.99	651818.43	829,921	756,058,031	30.183	9.694
912	2865.13	653250.21	831,744	758,550,528	30.199	9.698
913	2868.27	654683.56	833,569	761,048,497	30.216	9.701
914	2871.42	656118.48	835,396	763,551,944	30.232	9.705
915	2874.56	657554.98	837,225	766,060,875	30.249	9.708
916	2877.70	658993.04	839,056	768,575,296	30.265	9.712
917	2880.84	660432.68	840,889	771,095,213	30.282	9.715
918	2883.98	661873.88	842,724	773,620,632	30.298	9.718
919	2887.12	663316.66	844,561	776,151,559	30.315	9.722
920	2890.27	664761.01	846,400	778,688,000	30.331	9.726
921	2893.41	666206.92	848,241	781,229,961	30.348	9.729
922	2896.55	667654.41	850,084	783,777,448	30.364	9.733
923	2899.69	669103.47	851.929	786,330,467	30.381	9.736
924	2902.83	670554.10	853,776	788,889,024	30.397	9.740
925	2905.97	672006.30	855,625	791,453,125	30.414	9.743
926	2909.12	673460.08	857,476	794,022,776	30.430	9.747
927	2912.26	674915.42	859,329	796,597,983	30.447	9.750
928	2915.40	676372.33	861,184	799,178,752	30.463	9.754
929	2918.54	677830.82	863,041	801,765,089	30.479	9.757
930	2921.68	679290.87	864,900	804,357,000	30.496	9.761
931	2924.82	680752.50	866,761	806,954,491	30.512	9.764
932	2927.96	682215.69	868,624	809,557.568	30.529	9.768
933	2931.11	683680.46	870,489	812,166,237	30.545	9.771
934	2934.25	685146.80	872,356	814,780,504	30.561	9.775
935	2937.39	686614.71	874,225	817,400,375	30.578	9.778
936	2940.53	688084.19	876,096	820.025,856	30.594	9.783
937	2943.67	689555.24	877,969	822,656,953	30.610	9.785
938	2946.81	691027.86	879,844	825,293,672	30.627	9.789
939	2949.96	692502.05	881,721	827,936,019	30.643	9.792
940	2953.10	693977.82	883,600	830,584,000	30.659	9.796
941	2956.24	695455.15	885,481	833,237,621	30.676	9.799
942	2959.38	696934.06	887,364	835,896,888	30.692	9.803
943	2962.52	698414.53	889,249	838,561,807	30.708	9.806
944	2965.66	699896.58	891,136	841,232,384	30.724	9.810
945	2968.81	701380.28	893,025	843,908,625	30.741	9.813
946	2971.95	702865.38	894,916	846,590,536	30.757	9.817

Number, or Diameter.	Circumference.	Circular Area.	Square.	Cube.	Square Root.	Cube Root.
947	2975.09	704352.14	896,809	849,278,123	30.773	9.820
948	2978.23	705840.47	898,704	851,971,392	30.790	9.823
949	2981.37	707330.37	900,601	854,670,349	30.806	9.827
950	2984.51	708821.84	902,500	857,375,000	30.822	9.830
951	2987.66	710314.88	904,401	860,085,351	30.838	9.834
952	2990.80	711809.58	906,304	862,801,408	30.854	9.837
953	2993.94	713305.68	908,209	865,523,177	30.871	9.841
954	2997.08	714803.48	910,116	868,250,664	30.887	9.844
955	3000.22	716302.76	912,025	870,983,875	30.903	9.848
956	3003.36	717803.66	913,936	873,722,816	30.919	9.851
957	3006.50	719306.12	915,849	876,467,493	30.935	9.854
958	3009.65	720810.16	917,764	879,217,912	30.951	9.858
959	3012.79	722315.77	919,681	881,974,079	30.968	9.861
960	3015.93	723822.95	921,600	884,736,000	30.984	9.865
961	3019.07	725331.70	923,521	887,503,681	31.000	9.868
962	3022.21	726842.02	925,444	890,277,128	31.016	9.872
963	3025.35	728353.91	927,369	893,056,347	31.032	9.875
964	3028.50	729867.37	929,296	895,841,344	31.048	9.878
965	3031.64	731382.40	931,225	898,632,125	31.064	9.881
966	3034.78	732899.01	933,156	901,428,696	31.080	9.885
967	3037.92	734417.18	935,089	904,231,063	31.097	9.889
968	3041.06	735936.93	937,024	907,039,232	31.113	9.892
969	3044.20	737458.25	938,961	909,853,209	31.129	9.895
970	3047.35	738981.13	940,900	912,673,000	31.145	9.899
971	3050.49	740505.59	942,841	915,498,611	31.161	9.902
972	3053.63	742031.62	944,784	918,330,048	31.177	9.906
973	3056.77	743559.22	946,729	921,167,317	31.193	9.909
974	3059.91	745088.39	948,676	924,010,424	31.209	9.912
975	3063.05	746619.13	950,625	926,859,375	31.225	9.916
976	3066.19	748151.44	952,576	929,714,176	31.241	9.919
977	3069.34	749685.32	954,529	932,574,833	31.257	9.923
978	3072.48	751220.78	956,484	935,441,352	31.273	9.926
979	3075.62	752757.80	958,441	938,313,739	31.289	9.929
980	3078.76	754296.40	960,400	941,192,000	31.305	9.933
981	3081.90	755836.56	962,361	944,076,141	31.321	9.936
982	3085.04	757378.30	964,324	946,966,168	31.337	9.940
983	3088.19	758921.61	966,289	949,862,087	31.353	9.943
984	3091.33	760466.48	968,256	952,763,904	31.369	9.946
985	3094.47	762012.93	970,225	955,671,625	31.385	9.950
986	3097.61	763560.95	972,196	958,585,256	31.401	9.953
987	3100.75	765110.54	974,169	961,504,803	31.416	9.956
988	3103.89	766661.71	976,144	964,430,272	31.432	9.960
989	3107.04	768214.44	978,121	967,361,669	31.448	9.963
990	3110.18	769768.74	980,100	970,299,000	31.464	9.966
991	3113.32	771324.61	982,081	973,242,271	31.480	9.970
992	3116.46	772882.06	984,064	976,191,488	31.496	9.973
993	3119.60	774441.07	986,049	979,146,657	31.512	9.977
994	3122.74	776001.66	988,036	982,107,784	31.528	9.980
995	3125.89	777563.82	990,025	985,074,875	31.544	9.983
996	3129.03	779127.54	992,016	988,047,936	31.559	9.987
997	3132.17	780692.84	994,009	991,026,973	31.575	9.990
998	3135.31	782259.71	996,004	994,011,992	31.591	9.993
999	3138.45	783828.15	998,001	997,002,999	31.607	9.997
1000	3141.60	785398.16	1,000,000	1,000,000,000	31.623	10.000

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